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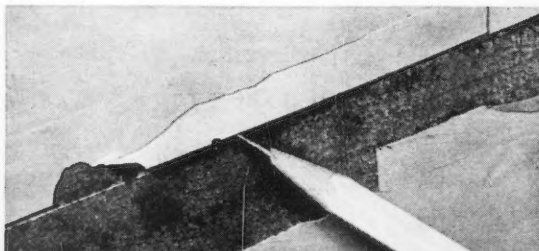
Vol. 14

MARCH, 1958

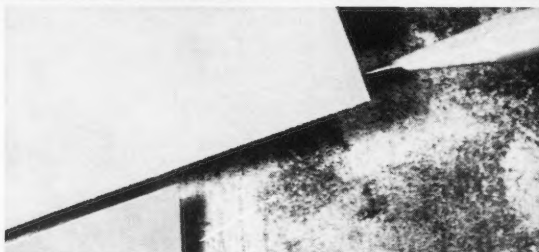
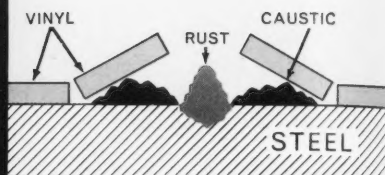
No. 3

PUZZLED ABOUT PRIMERS?

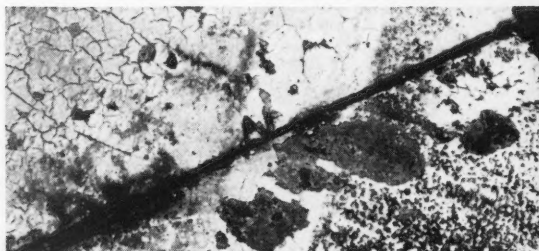
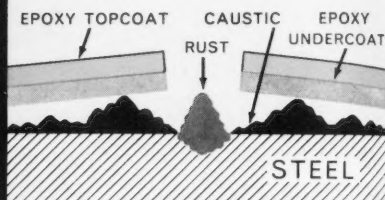
Here are tests you can duplicate



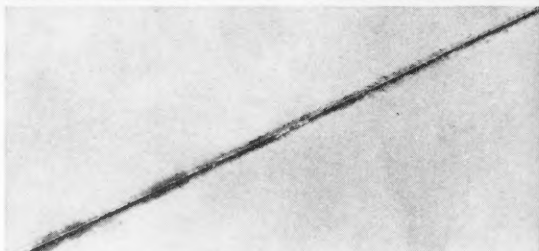
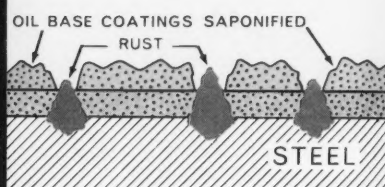
TEST 1—One coat of self-priming vinyl. Coating breaks away (L) due to severe undercutting (R), exposing metal to progressive corrosion.



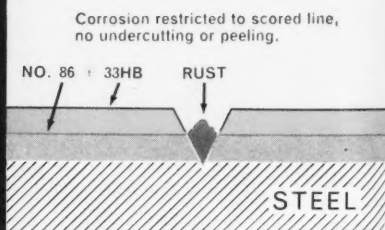
TEST 2—Epoxy primer, epoxy topcoat. Coating lifts off in single sheet (L) as adhesion fails (R), exposing entire surface to corrosion.



TEST 3—Oil primer, oil topcoat. Both coats fail completely (L) as underfilm caustic reacts on their oils to form soaps (R).



TEST 4—Amercoat's No. 86 inhibitive primer and No. 33HB vinyl topcoat. Corrosion restricted to scored line (L), no undercutting or peeling (R).



The purpose of these accelerated tests is to show what happens when various types of coatings are exposed to a typical corrosive environment. Four clean steel panels, free from mill scale and rust, were coated with different combinations of primers and topcoats. Each was scribed to bare metal and immersed in salt water in the presence of free oxygen, for two weeks.

As caustic deposits formed over cathodic areas of the steel in tests 1, 2 and 3, failure occurred in three ways. The vinyl, though not directly attacked, was undercut as caustic

spread beneath the film and destroyed adhesion. The epoxy coating, known for critical adhesion to smooth metal, proved impervious to caustic attack. It was, however, lifted in its entirety as moisture spread beneath the surface. The entire oil paint film was quickly penetrated by the salt solution, creating widespread corrosion and caustic formation. The caustic then reacted with the oil to saponify the film.

In the fourth test the corrosion was limited to the score mark. Reason: Amercoat No. 86 Primer resists undercutting and adheres tenaciously,

inhibiting electrolytic corrosive action.

The conclusions are clear. To provide long term protection in corrosive service, start with Amercoat No. 86 Primer, which provides a sound and lasting base for quality topcoats such as Amercoat No. 33HB.

Write today for complete data on Amercoat No. 86, and have the details on hand when planning your next important coating job.

Amercoat CORPORATION
109 Dept. 66
4809 Firestone Blvd., South Gate, Calif.



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Corrosion

devoted entirely to corrosion
research and control

Published monthly as its official journal, by the National Association of Corrosion Engineers, Inc., at Houston, Texas, U. S. A., as a permanent record of progress in corrosion control.

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were evaluated from the standpoint of mechanical properties as well as anti-corrosive effect. As to the anti-corrosive power, metallic test pieces including couples to steel pieces were also tested in aqueous solution of Dichan.—JSPS. 14251

5.8.2

Cyclohexylamine Carbonate as a Volatile Corrosion Inhibitor. C. A. RHODES. *Corrosion Prevention & Control*, 4, No. 4, 37-39, 42 (1957) April.

Extensive series of laboratory tests and practical tests showed that cyclohexylamine carbonate (CHC) vapor is in many respects the most effective volatile corrosion inhibitor yet discovered. CHC gives almost immediate protection in enclosed space due to its relatively high rate of volatility, and provides protection at an appreciable distance. In addition to its powerful rust-inhibiting action on ferrous metals, CHC protects tin-plate and solder, cadmium-plate, nickel, Monel, lead, zinc, and aluminum. In all cases except copper and magnesium and some of their alloys, water droplets condensed on metal do not interfere with inhibitive action of CHC. Graph shows effect of CHC addition on steel specimens in supersaturated atmospheres containing sulfur dioxide. Results of protecting mild steel evaporating pans, used for making beet sugar, during storage are discussed.—INCO. 14171

5.8.2, 4.4.7, 4.4.6, 5.5.1

A Laboratory Study of N-Oleoyl Sarcosine as a Rust Inhibitor in Some Petroleum Products. ROBERT M. PINES and JOHN D. SPIVACK. *Corrosion*, 13, No. 10, 690t-694t (1957) October.

Laboratory studies indicate that N-oleoyl sarcosine (I) is an effective oil soluble rust inhibitor in solution in gasoline, mineral oil and silicone lubricants.

Rusting tests used included: Turbint Oil Rusting Test (ASTM D665-54) a static immersion test, Humidity Cabinet Test (JAN H-792), Static Water Drop Test (MIL-L-17353 Bu. Ord.). In addition, a number of auxiliary tests were run to indicate the effect of (I) on other properties of the test liquid.

Hydrocarbon solutions of N-oleoyl sarcosine are particularly effective in preventing rusting in the presence of synthetic sea water and in resisting water extraction of the inhibitor. 14223

5.8.2, 5.6.1

Testing for Package Materials Treated with Volatile Corrosion Inhibitor. (In Japanese.) First Sub-Committee (Sec. B) of the Committee of Preventing Corrosion, Japan Society for the Promotion of Science. *Corrosion Engineering*, 6, No. 2, 84-86 (1957) March.

The anti-corrosive effect on steel of domestic-made products of VPI paper, e.g. package materials coated with dicyclohexylamine nitrate, were evaluated by testing methods specified in U.S.A. specification, MIL-P-3420—JSPS. 14228

5.8.3, 2.3.4

Researches on Corrosion and Inhibition. G. S. GARDNER. *Am. Chemical Paint Co. J. Franklin Inst.*, 263, No. 6, 523-533 (1957) June.

Study of corrosion velocity of steel in dilute acetic acid, in presence of an oil phase and in presence and absence of an organic inhibitor. Values of s , the fractional surface covered by adsorbed inhibitor, are calculated from experiments for each inhibitor concentration c .

Langmuir equation in the form

$$1/s = (1/b) (1/c) + 1$$

is solved graphically by plotting observed values of $(1/s)$ against $(1/c)$. It is suggested that value of Langmuir constant b , found in this manner, can be used for over-all evaluation of an organic corrosion inhibitor. Tables, graphs.—INCO. 14266

5.8.3, 3.6.6, 6.4.2, 6.4.4

Investigation of Inorganic Inhibitors for Minimizing Galvanic Corrosion of Magnesium Coupled to Aluminum. SARA J. KETCHAM and WALTER BECK. *Corrosion*, 13, No. 9, 608t-614t (1957) Sept.

A fundamental study has been conducted of some inhibitors found to be effective in reducing galvanic corrosion between magnesium alloy AZ31B and aluminum alloy 2024-T3 in saline solutions. The object of the study was to determine the mechanism of protection afforded by the inhibitors, $Mg(VO_3)_2$, $BaK_2(CrO_4)_2$ and CaS , singly and in combination. The effect of these inhibitors on the polarization characteristics of the metals was determined with the electrodes isolated in separate compartments, bridging being accomplished with agar-sodium chloride bridges. In this group of tests, the polarization potentials, recovery potentials and corrosion currents were measured, the latter by means of the zero resistance ammeter circuit. Additional tests were made with the electrodes in the same beaker, corrosion currents and corrosion rates being determined under these conditions.

Correlation of results from the potential, corrosion current, and corrosion rate data indicates that the $Mg(VO_3)_2$ and $BaK_2(CrO_4)_2$ polarize the aluminum strongly in the anodic direction, thereby reducing the galvanic current and the weight loss of magnesium.

Weight loss on aluminum was related to the increase in alkalinity occurring in experiments made in the same beaker.

Corrosion current measurements may serve as a useful tool for the determination of effectiveness of inhibitors, but the method should not be used indiscriminately.

Practical conclusions should only be drawn from the results obtained in experiments with both metals exposed in the same compartment. 14204

5.8.3, 3.8.3

The Conditions of Passivation of Iron by Chromates, Molybdates, Tungstates and Vanadates. (In French.) M. POURBAIX and N. DE ZOUBOV. Centre Belge d'Etude de la Corrosion. Rapport Technique No. 43, January 1957, 6 pp. Available from: Cebelcor, 21 rue des Drapiers, Brussels, Belgium.

With the aid of electrochemical equilibrium diagrams and a new hypothesis, the conditions of pH and of electrode voltage were defined for which 0.01 molar solutions of chromate, molybdate, tungstate or vanadate can theoretically have an activating or passivating action on iron.—BTR. 14146

5.8.3, 4.3.2

Iron Corrosion in Hydrochloric Acid in the Presence of Inhibitors at Various Temperatures. Part I. I. P. ANOSHCHENKO. *J. Applied Chem., USSR (Zhur. Priklad. Khim.)*, 30, No. 3, 393-400 (1957).

Effect of potassium bromide, urotropine and acridine in inhibiting iron corrosion in 6N hydrochloric acid at 20, 40, 60 and 80 degrees is studied by means of polarization curves. 9 figures,

5 references.—ATS. Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey. 14266

5.8.3, 4.3.2

The Corrosion of Iron in Hydrochloric Acid in the Presence of Inhibitors at Various Temperatures. Part II. I. P. ANOSHCHENKO. *J. Applied Chem., USSR (Zhur. Priklad. Khim.)*, 30, No. 4, 533-528 (1957).

Effect of urotropine, potassium bromide, acridine and methanol corrosion inhibitors is studied at 20, 40, 60 and 80 degrees. 3 tables, 2 figures, 3 references.—ATS. Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey. 14270

5.9 Surface Treatment

5.9.2

Metal Surface: Pickling for Galvanizing. (In French.) A. HERZ. *Metallurgie*, 89, No. 2, 125-127 (1957) Feb.

A brief introduction on the respective merits and failings of the various methods of pickling is followed by a description of the oxidation of steel with respect to the order in which the three possible oxides are formed. Hydrochloric and sulfuric acids are then compared as pickling agents. The article concludes with a note on the influences of hydrogen evolution and inhibitors and the effects, rapid detection and elimination of chance occurrences of arsenic.—ZDA. 14270

5.9.2

Structure and Aptitude to Pickling of the Scale of Hot-Rolled Strip. (In German.) WINFRIED DAHL and WERNER LUEG. *Stahl und Eisen*, 77, No. 13, 845-853 (1957) June 27.

Testing method. Metallographic examination of strip of different origin. Pickling tests with continuous record of the loss in weight, of the potential and intensity of current. Interpretation of the test results.—SE. 14236

5.9.2, 5.9.4

Electrolytic and Chemical Polishing. P. A. JACQUET. *Metallurgical Reviews*, 1, No. 2, 157-238 (1956).

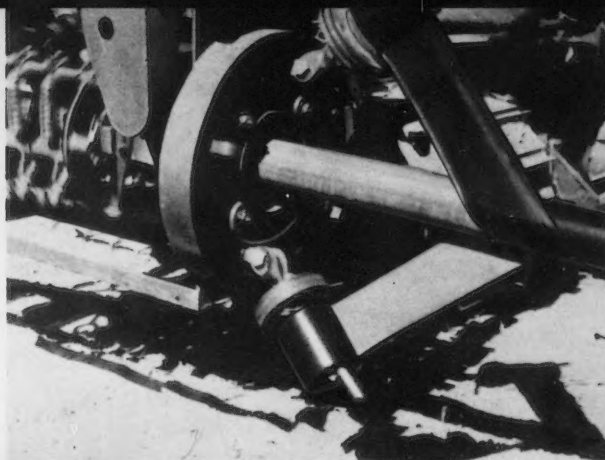
A survey covering problems relating to methods of electrolytic and chemical polishing, excluding scientific and technical applications. The three main parts deal respectively with the definition of the state of a metallic surface; history and principles of the polishing processes and mechanisms suggested; and comparative characteristics of surfaces polished mechanically, anodically and chemically. Two appendices give practical details of electrolytic and chemical polishing methods, listed alphabetically under metals. This paper, which is extensively documented, is indispensable to all with any interest in this field.—BNF. 14102

5.9.3

Metal Cleaning and Finishing by the Airless Abrasive Blasting Process. F. W. PEDROTTY. *J. Inst. Production Engrs.*, 36, 128-135 (1957) Feb.

Cleaning castings, removing scale from forgings, removing heat treating scale, cleaning weldments and preparing surfaces for final finishing by airless abrasive process. Types and sizes of ferrous abrasives described.—MR. 13856

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OF DEARBORN NO. 655 F.O.S. SAFE-T-CLAD TAPE

PHYSICAL	TEST METHOD	DATA
Color		Black
Backing Material		Polyethylene
Adhesive		Synthetic
Thickness:		
Backing	ASTM D-1000-48T	10 mils
Adhesive	ASTM D-1000-48T	3 mils
Total Thickness	ASTM D-1000-48T	13 mils
Moisture Vapor Transmission Rate	JAN-P-127	0.2 gm./100 sq. in./24 hr.
Moisture Absorption	ASTM D-570-42	0.02%
Tensile Strength (2" width) (Machine direction)	ASTM D-1000-48T Mod.	30 lbs./1" grab
Tensile Strength (2" width) (Cross direction)	ASTM D-1000-48T Mod.	30 lbs./1" grab
Elongation (Machine direction)	ASTM D-1000-48T Mod.	500% plus
Elongation (Cross direction)	ASTM D-1000-48T Mod.	500% plus
Tear Resistance (Machine direction)	ASTM D-689	Not less than 950 gm.
Tear Resistance (Cross direction)	ASTM D-689	Not less than 950 gm.
Adhesion to steel	ASTM D-1000-48T Mod.	Min. 43 oz./1" width
Adhesion to backing (180° pull)	ASTM D-1000-48T Mod.	Min. 32 oz./1" width
*Temperature performance range	Dearborn	-30° F. to 200° F.
Weatherometer	Dearborn	No effect/70 hrs.
ELECTRICAL	TEST METHOD	DATA
Dielectric Strength	ASTM D-1000-48T Mod.	Min. 15,000 volts
Insulation Resistance	ASTM D-257	One million megohms
RESISTANCE TO:	TEST METHOD	DATA
Acids, Inorganic and Organic (Aqueous solutions)	Dearborn	Excellent
Alcohols (Water soluble)	Dearborn	Excellent
Alkalies	Dearborn	Excellent
Amines (Aqueous solutions)	Dearborn	Excellent
Animal Acids	Dearborn	Excellent
Bacteria	Dearborn	Excellent
Fungi	Dearborn	Excellent
Hydrocarbons, Aliphatic	Dearborn	Fair
Hydrocarbons, Aromatic	Dearborn	Fair
Ketones, Esters (Aqueous solutions)	Dearborn	Good
Oils	Dearborn	Fair
Salt Water	Dearborn	Excellent
Vegetable Acids	Dearborn	Excellent
Water	Dearborn	Excellent
Weathering	Dearborn	Excellent

*Dearborn #655 F.O.S. Safe-T-Clad Tape will retain its physical quality within this range of temperatures, but application should only be undertaken at temperatures above 32°F.

STANDARD ROLL 13 Mils Thick—On 1½-in. ID Cores STANDARD PACKING

Roll Size	Rolls Per Case	Rolls Per Square	Squares Per Case
1" x 100 Ft.	48	12	4
2" x 100 Ft.	24	6	4
4" x 100 Ft.	12	4	4
6" x 100 Ft.	8	2	4
9" x 100 Ft.	4	1½	3

We can furnish rolls in 200 and 300 foot lengths, and widths not shown at left, upon request, and subject to manufacturing availability. Dearborn #655 F.O.S. Safe-T-Clad Tape is sold in case lots only.

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Traveliner Rolls can be manufactured to order in 400, 600 and 800 foot roll lengths on 3 inch I.D. cores in 10 inch and 15 inch widths only.

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Basic engineering information about DURIRON impressed current anodes for cathodic protection.

Protection of an Office Building Water Service Tank

THE PROBLEM: The cathodic protection of two 2600 gallon office building water service tanks. Aluminum anodes previously used in the installation had a comparatively short service life and required annual replacement. The continually increasing surface resistance of the aluminum anodes also required periodic rectifier adjustments to maintain an adequate protective current.

THE INSTALLATION: The tank is a single structure divided by a bulkhead to form two separate water storage units of identical size. The anodes were laid out to miss internal bracing, floats, and free-space for hatch opening. A single Duriron Type D (2" x 60") anode was first tested in parallel to fifteen 5 month old aluminum anodes (1-1/16" x 72") to determine its relative merits. Although the Duriron anode had slightly higher surface resistance when first installed, it showed no tendency for this surface resistance to increase and within 2 to 3 months was passing over twice as much current as the average current from the aluminum anodes.

After 311 days of the testing period the original anode proved so successful that all fifteen aluminum anodes (having reached the end of their useful life) were replaced with Duriron Type A (1" dia. x 60" long) anodes. One and one-half standard lengths were joined end to end making each anode assembly 7.5 feet long. Fifteen assemblies, together with the original test anode, were installed as shown in Fig. 2.

The test anode was inspected after more than two years of operation with the following results:

Total energy discharge—8700 ampere hours
Weight loss—3 ounces
Rate of loss—0.19 lbs. per ampere per year
Current density, over a 10 month period—0.14 to 0.21 amps per square foot

THE PERFORMANCE TO DATE: Five of the fifteen Duriron anodes installed on a permanent basis were inspected after 440 days of operation. The following table illustrates the results of this inspection.

Inspection Results After 440 Days Service

Anode Number	Total Energy Discharge (Ampere Hrs.)	Weight Loss (Ounces)	Consumption Rate Lbs./Amp./Yr.	Current Density (Amps per Square Foot)
1	3400	1	0.160	0.21 to 0.28
2	3181	3/4	0.086	0.20 to 0.27
3	3600	2	0.300	0.22 to 0.30
4	3000	3/4	0.045	0.17 to 0.23
5	3400	1 1/4	0.240	0.22 to 0.30

Incidental Data at Inspection Time:

A—Water resistivity in this tank was approximately 14,000 ohm-cm.

B—Average potential impressed on anodes was 25 volts, d-c.

A careful inspection was also made of the submerged joints of the five anodes. While a single neoprene washer appeared to adequately protect the submerged joint, polyethylene or polyvinylchloride tapes were also used over the joints to give further protection. All joints were found to be in excellent condition, although it was concluded that the taping of joints afforded little, if any, extra protection. There was no evidence of attack on the Monel inserts or the Everdur studs.

Corrosion attack on Duriron impressed current anodes is negligible at low current densities under the conditions of this installation. The Duriron anodes showed no appreciable increase in surface resistance during the entire period.

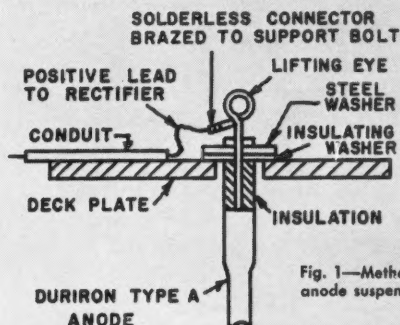


Fig. 1—Method of anode suspension

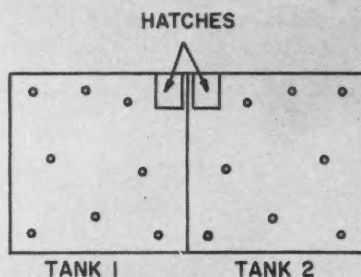


Fig. 2—Illustration of anode spacing

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Another Tough Protection Job — Solved by TARSET[®]

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Providing more durable docking facilities was accomplished by replacing the wood piling with cylindric steel cells, constructed with steel piling plates driven into the river bed and strengthened with a fill of washed sand and gravel.

But the problem *then* was to protect the cells from corrosion, and from contact with the heavy barges.

Pitt Chem *Tarset* was selected for the job for two principal reasons:

1. *Tarset* is a unique and patented combination of coal tar and epoxy resin. In three years of service history, it has proven extremely resistant to severest moisture conditions.

2. *Tarset's* adhesion to metal is so great that it is virtually impossible to remove except by sand-blasting. So *Tarset* was ideal for resisting abrasion from barge movement.

What's *your* most troublesome corrosive material? Chemicals? Petroleum? Industrial Wastes? *Tarset* has an amazing performance record against all of them. • Ask for complete information about revolutionary *Tarset* today! A letter or call will receive our prompt attention.



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Vol. 14

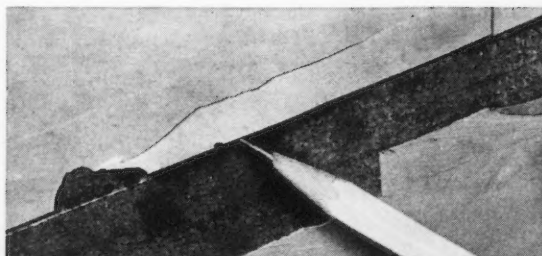
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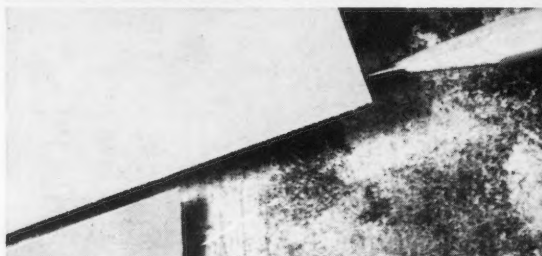
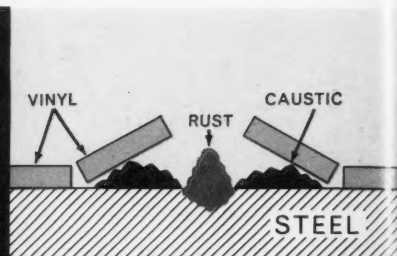
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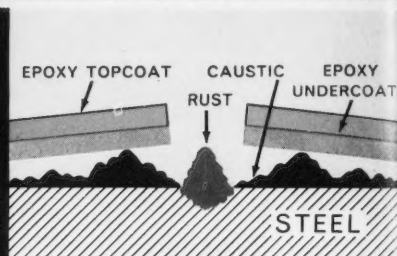
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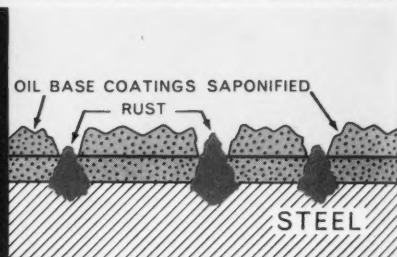
TEST 1—One coat of self-priming vinyl. Coating breaks away (L) due to severe undercutting (R), exposing metal to progressive corrosion.



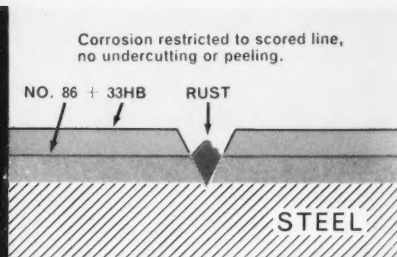
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TEST 3—Oil primer, oil topcoat. Both coats fail completely (L) as underfilm caustic reacts on their oils to form soaps (R).



TEST 4—Amercoat's No. 86 inhibitive primer and No. 33HB vinyl topcoat. Corrosion restricted to scored line (L), no undercutting or peeling (R).



The purpose of these accelerated tests is to show what happens when various types of coatings are exposed to a typical corrosive environment. Four clean steel panels, free from mill scale and rust, were coated with different combinations of primers and topcoats. Each was scribed to bare metal and immersed in salt water in the presence of free oxygen, for two weeks.

As caustic deposits formed over cathodic areas of the steel in tests 1, 2 and 3, failure occurred in three ways. The vinyl, though not directly attacked, was undercut as caustic

spread beneath the film and destroyed adhesion. The epoxy coating, known for critical adhesion to smooth metal, proved impervious to caustic attack. It was, however, lifted in its entirety as moisture spread beneath the surface. The entire oil paint film was quickly penetrated by the salt solution, creating widespread corrosion and caustic formation. The caustic then reacted with the oil to saponify the film.

In the fourth test the corrosion was limited to the score mark. Reason: Amercoat No. 86 Primer resists undercutting and adheres tenaciously,

inhibiting electrolytic corrosive action.

The conclusions are clear. To provide long term protection in corrosive service, start with Amercoat No. 86 Primer, which provides a sound and lasting base for quality topcoats such as Amercoat No. 33HB.

Write today for complete data on Amercoat No. 86, and have the details on hand when planning your next important coating job.

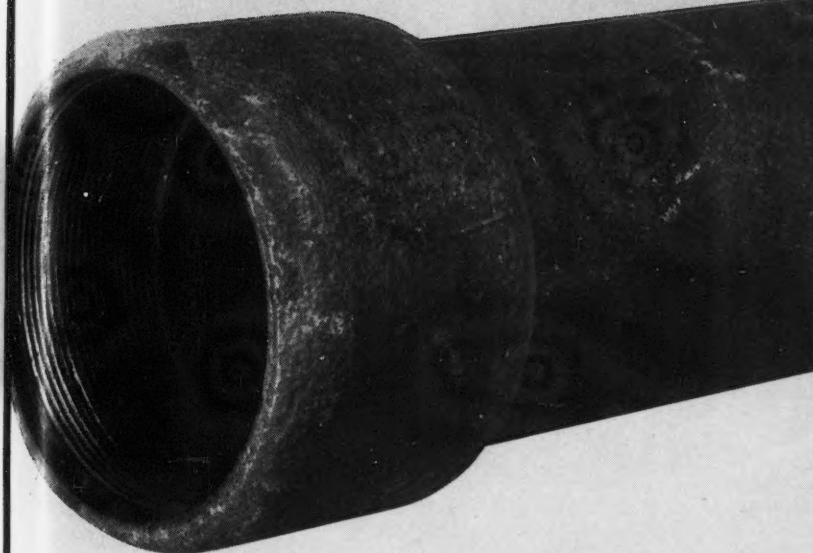


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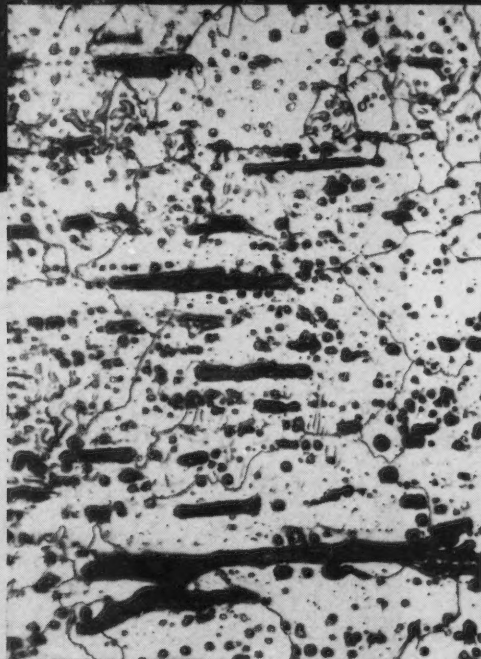
other Wrought Iron case against corrosion

58

YEARS OF SERVICE



Longitudinal photomicrograph S-64-2 (100x) shows a typical area—parallel to rolling—of the microstructure observed in the subject 5-inch wrought iron pipe.



Metallurgical Report 6628—Underground Oil Line*

This report deals with the metallurgical examination of a length of 5-inch wrought iron pipe, submitted to our laboratory for investigation and comment.

The sample submitted has been in service 58 years, yet found to be in excellent condition. Note that the scale is tightly adherent to the surface of the pipe.

ROCKWELL HARDNESS

A cross-sectional ring was prepared for hardness determination. Hardness values taken around the cross-sectional ring indicated a B66 hardness typical for wrought iron pipe and showed that the strength and ductility were likewise normal.

CHEMICAL ANALYSIS

Carbon—.018%; Manganese—.040%; Phosphorus—.0236%; Sulphur—.019%; Silicon—.186%; Iron Silicate—3.54%.

SUMMARY

Results of the laboratory examination serve as positive identification of the subject sample as wrought iron. The excellent state of preservation of this sample after more than a half-century of service is indicative of wrought iron's longevity in corrosive service. A. M. Byers Company, Clark Building, Pittsburgh 22, Pennsylvania.

*Name of actual installation given on request.

Write for free cloth-bound book, *Wrought Iron: Its Manufacture, Characteristics and Applications.*

BYERS

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Whether your requirements call for the unmatched throwing power of Galvomag® magnesium anodes or a lower potential unit, magnesium is your best bet. For facts, figures and technical information, get in touch with one of the firms listed below or write to us. THE DOW CHEMICAL COMPANY, Midland, Michigan, Dept. MA 1436R-1

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Corrosion

devoted entirely to corrosion
research and control

Published monthly as its official journal, by the National Association of Corrosion Engineers, Inc., at Houston, Texas, U. S. A., as a permanent record of progress in corrosion control.

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Outstanding Features of April Issue

Technical Topics: Impressed Current Anodes Installed and Backfilled at Depth of 350 Feet (Conference paper); Protective Coatings Standardization in a Multi-Plant Chemical Operation.

● Also an outstanding array of papers in the Technical Section (See list on Page 12), news, abstracts and other features.

Look for The Report on SAN FRANCISCO CONFERENCE

May CORROSION will have a report on the activities at the 14th Annual NACE Conference and Exhibition to be held March 17-21 at the San Francisco Civic Auditorium. This report on the technical program, exhibits and social events will be presented in text and photographs. If you can't attend the next best thing is to read the conference report.

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THIS MONTH'S COVER—This scene at the registration desk in University of Houston—Houston Section "Corrosion Control Short Course for Pipeliners" will be repeated many times this year. The Houston course is in its third year, but others on many subjects have been held in the United States, Canada and Mexico, some for as many as seven consecutive years. This educational activity is among NACE's most important contributions to industry.



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requirement for potential. This resistance decreases rapidly by extending the length of the anode. Therefore, with 50% increased length, with no increase in anode weight, a higher current output can be obtained from the H-1 alloy anode than from the "High Potential" anode.

3. In low resistance soils and in sea water, where 90% of corrosion generally occurs, the H-1 alloy anode develops the proper amount of current to protect against corrosion. This is a fact which has been proved over many years in thousands of installations. By using the high potential anode in low resistance soils more current is generated than is actually needed to obtain full protection.

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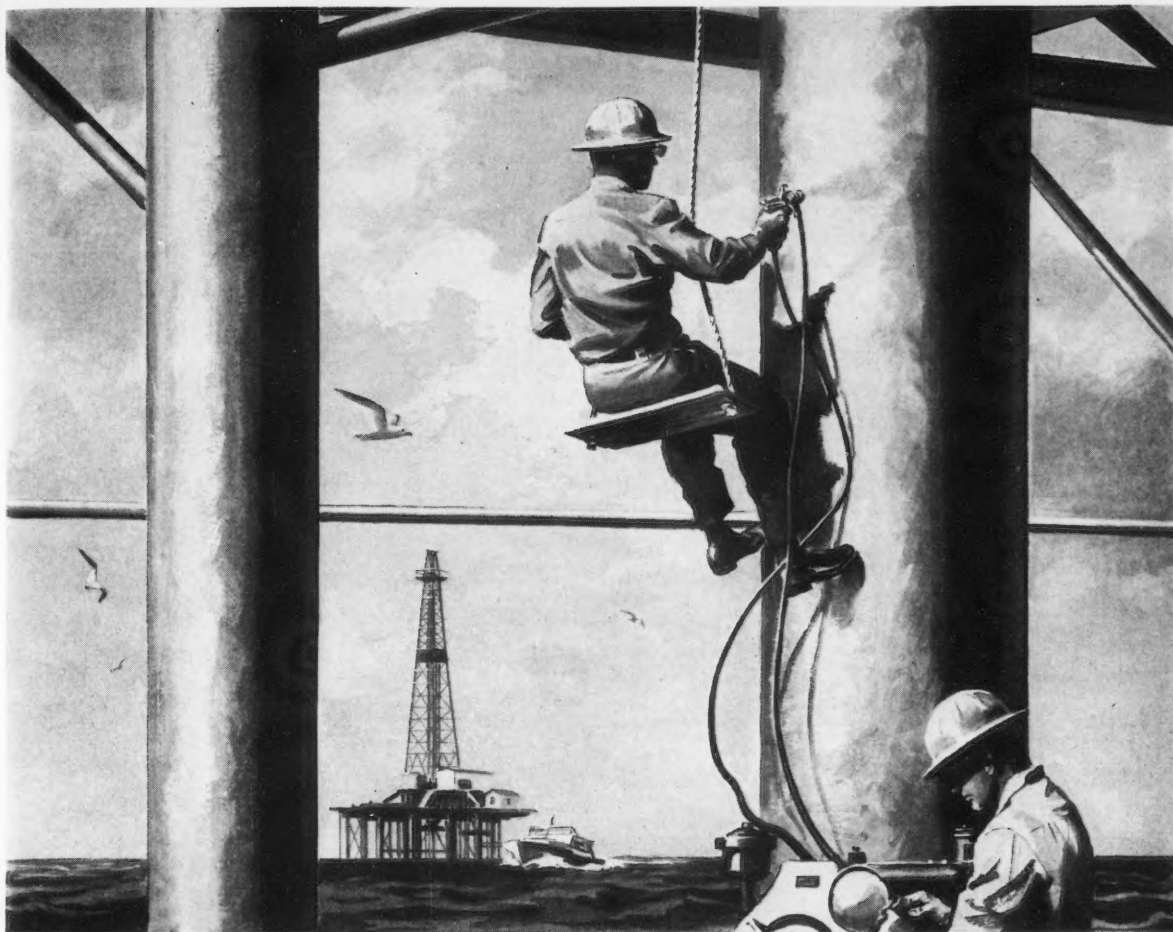
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• For detailed information on how Humble's protective coatings can save you money, call your Humble salesman, or phone or write:

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Sales Technical Service
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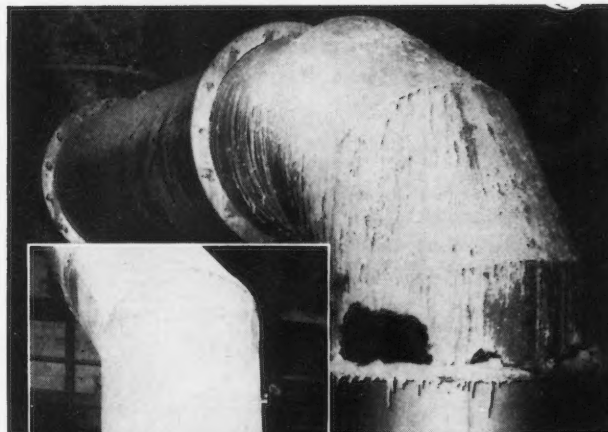
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In venting systems for alum evaporators and digesters at Cyanamid's Warners, N. J., plant, carbon steel breeches and stacks required frequent maintenance, failed after two or three years of service.

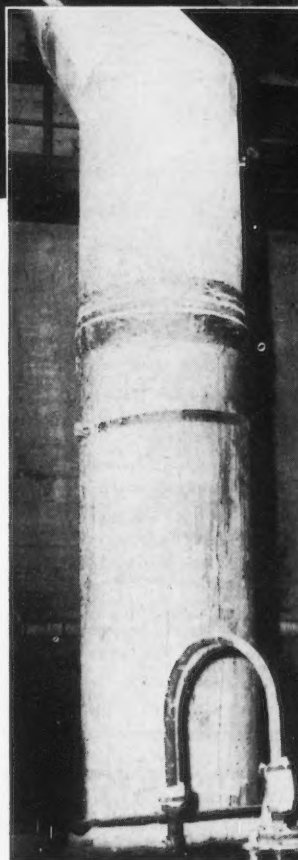
Breeches and stacks molded of reinforced LAMINAC resin by Carl N. Beetle Plastics Corporation were installed as replacements. In the 84' stack installation, pictured at right, reinforced LAMINAC has served for more than three years without maintenance!

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Carbon steel breeching, $\frac{3}{16}$ " thick, in this alum evaporator at Cyanamid's Warners plant failed after 3 years, was replaced with reinforced LAMINAC.



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T-9D Correlation of Evaluation of Preservatives

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TECHNICAL ARTICLES SCHEDULED FOR PUBLICATION IN APRIL

The following papers have been scheduled for publication in CORROSION's Technical Section in April:

Basic Concepts and Practical Aspects of Field Corrosion Investigations by M. A. Riordan

The Distribution of Soil Conductivities and Some Consequences by Gordon N. Scott

Inhibition of Corrosion of Mild Steel in $\text{NH}_4\text{NO}_3\text{-NH}_3\text{-H}_2\text{O}$ Solutions by Norman Hackerman, Ray M. Hurd and Earl L. Snavely

Cathodic Protection of Lead Cable Sheath in the Presence of Alkali from De-icing Salts by W. H. Bruckner and W. Wayne Lichtenberger

Heat Transfer Through Coated Metal Surfaces by Robert P. Lee

Controlling Corrosion in Coal-Chemical Plants by C. P. Larrabee and W. L. Mathay

Cathodic Protection of Iron at Higher Temperatures by G. R. Hoey and M. Cohen

On the Mechanism of Stress Corrosion of Austenitic Stainless Steels in Hot Aqueous Chloride Solutions by K. W. Leu and J. N. Helle

Corrosion of Concrete by Autotrophes by J. H. Rigdon and C. W. Beardsley

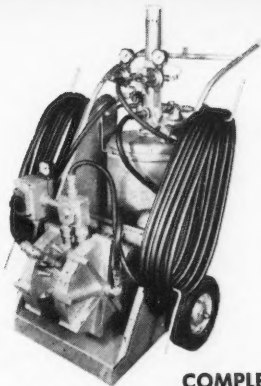
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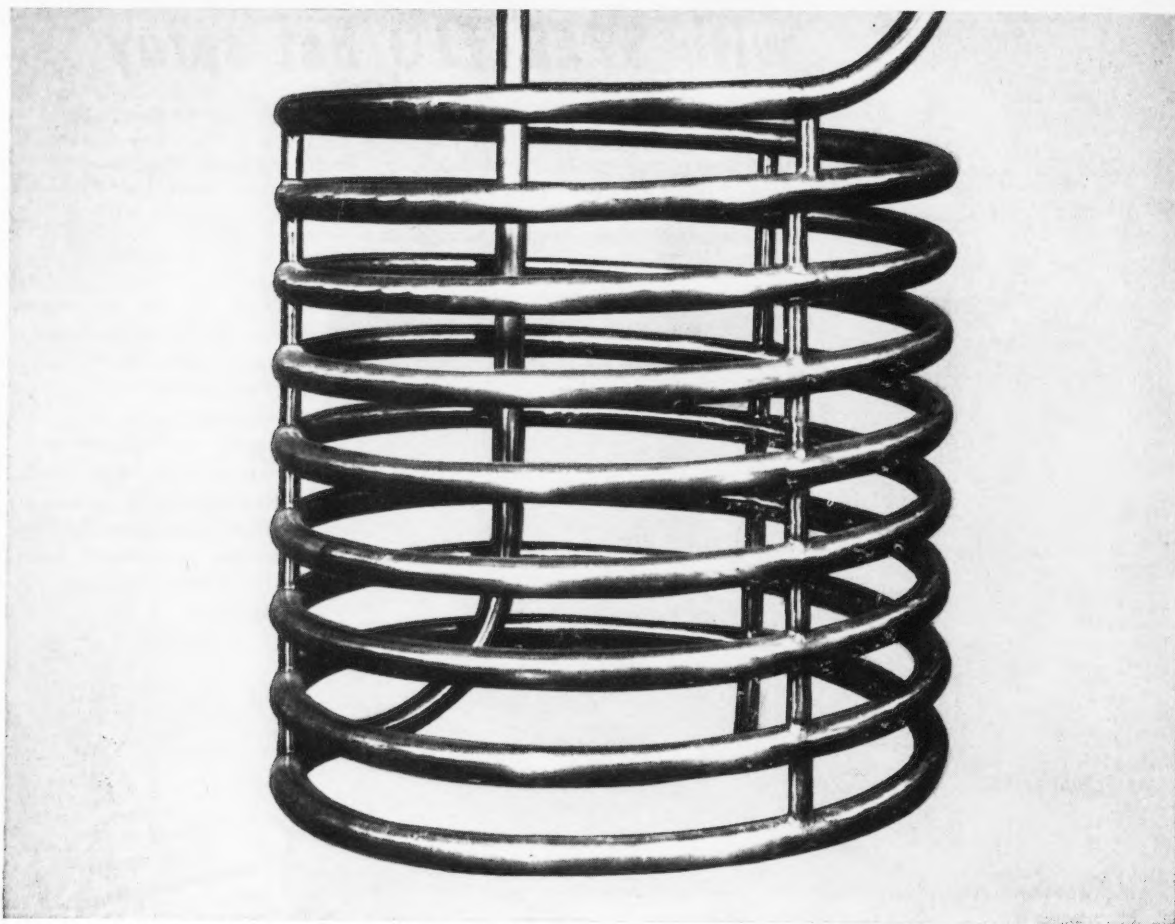


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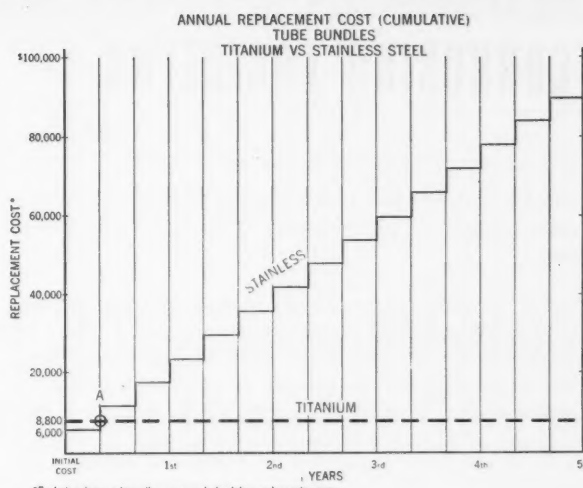
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A Technical Note

A Simplified Method of Preparing Solutions Of Glycerol and Water for Humidity Control*

By J. V. BRAUN and J. D. BRAUN

Introduction

IN THE course of research and routine laboratory work on corrosion of metals, it often is necessary to maintain a definite humidity in an enclosed space. There are two ways of providing a series of humidities by the use of solutions. One method is to use saturated solutions of different salts which are chosen for the humidities required. The other method is to make up from a suitable compound, solutions of varying concentrations which will furnish the necessary water vapor pressures. Only the second method will give a precise and evenly graded series of humidities.

Solutions of glycerol and water have several advantages over other materials which might be used for obtaining desired humidities. Homogeneous solutions varying from 0 to 100 percent water can be obtained easily and their exact composition determined by specific gravity measurements. In addition to this, solutions of glycerol-water are much less corrosive to metals than either saturated inorganic salt solutions or sulfuric acid. The only commonly used material which is corroded by glycerol is tin. All the other metals commonly tested in corrosion studies are completely unaffected by glycerol.¹

The recognized ASTM method² for making up glycerol-water solutions to furnish known relative humidities involves using a refractometer. Since this is a rather tedious method, the simpler process of correlating the specific gravity of glycerol-water solutions and percent relative humidity above them was investigated.

Previous work published^{3,4} on glycerol-water solutions for use in humidity control was limited primarily to relative humidities above 85 percent. In the



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JAMES V. BRAUN obtained a BS degree in chemical engineering from the University of Wisconsin in 1954. He then spent two years on active duty with the United States Air Forces at Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, working in the field of metal protection and corrosion. Upon release from military service in 1957 he entered employment in the Solid Rocket Propellant Section of the Power Plant Laboratory of Wright Air Development Center.

JAPNELL D. BRAUN received a BS in chemistry from the University of Florida, Gainesville, Fla., in 1951. Her work experience has been varied, including research in chemical economics at Stanford Research Institute, Palo Alto, Calif., and industrial experience in the manufacturing research department at Frigidaire Division, GMC, Dayton, Ohio. She then joined the Electrochemical and Corrosion Section of the Materials Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, as a chemist. She is now associated with Monsanto Chemical Co., Dayton, Ohio.

work done by Johnson⁵ only half of the points plotted were experimental values. The remainder of the graph of percent relative humidity vs specific gravity was filled in from calculated

Abstract

A simplified method of preparing solutions of glycerol and water for use in humidity control is described. The advantages of glycerol-water solutions over other solutions commonly used for humidity control in corrosion studies is discussed.

Solutions of glycerol and water were prepared in various concentrations and their specific gravities determined. The percent relative humidity over each solution was measured and plotted against specific gravity of the solution. The resulting smooth curve can be used in preparing humidity control solutions accurate to within one unit of percent relative humidity. 23.1

data. The experimental points plotted were mean percent relative humidity, not individual readings, and the temperature varied from 7 C to 23 C.

Experimental Work

Solutions of glycerol (C.P.) and water were prepared at 18 different concentrations, ranging from 0 to 100 percent glycerol. Approximately 100 cc of each glycerol-water solution was placed in a one quart wide-mouth bottle, with inlet and outlet glass tubing fitted in a rubber stopper. The atmosphere over the solution was cycled through a General Electric Dew Point Indicator by means of a White-Mist pump. The free air in the system was estimated as 50 cubic inches. This was pumped through the system at the rate of 50 cubic inches/minute. The jars were placed on side giving an exposed surface area of 15 square inches. One to two hours were allowed for equilibration and successive dew point readings were taken until no further change was noted.

The specific gravity of each solution was determined on a Westphal balance immediately following the final dew point reading. The specific gravities of several of the solutions also were meas-

* Submitted for publication April 19, 1957.

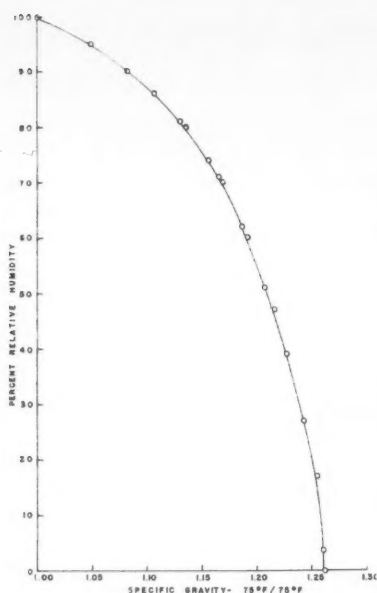


Figure 1—Relation between relative humidity over glycerol-water solutions and their specific gravities.

ured with a hydrometer. These readings are compared with those made on the Westphal balance in Table 1. The dew point, room temperature when the reading was made, and the specific gravity of each solution were tabulated and

TABLE 1—Relative Humidity Over Various Glycerol-Water Solutions

Specific Gravity*	Room Temp., Degrees F.	Dew Point Degrees F.	Percent Relative Humidity
1.000 (100... Water).....	74	74	100
1.049.....	74	72.5	95
1.082.....	75	73	90
1.107.....	75	70.5	86
1.130.....	74	68	81
1.135 (1.137)**..	76	69.5	80
1.156.....	75	66	74
1.165.....	75	65	71
1.168 (1.170)**..	74	64	70
1.186.....	76	62	62
1.191 (1.193)**..	75	60	60
1.207 (1.209)**..	76	57	51
1.216.....	77	55	47
1.227.....	75	48	39
1.243.....	68	32	27
1.255.....	69	22	17
1.260.....	75	-7	3.7
1.261 (Pure Glycerol).....	—	—	0

* Specific gravity measured on Westphal balance which was set to read 1.000 for distilled water at 75 F.

** These specific gravities were measured by a hydrometer for comparison.

the percent relative humidity above each solution was calculated from the dew point readings using a General Electric Co. psychrometric chart (see Table 1.). These values were plotted against the specific gravity of each solution (Figure 1.).

Conclusion

When the specific gravities of glycerol-water solutions are plotted against the percent relative humidity above these solutions, a smooth curve results (Figure 1.). These plotted values fall within a range of \pm one unit of percent relative humidity. The reproducibility of humidity over glycerol-water solutions has been shown to be very good. This graph should be useful in rapidly making up solutions that will furnish any required humidity. For all practical laboratory purposes the specific gravity can be measured with a hydrometer, as the deviation from the measurement with the Westphal balance was only between 0.2 and 0.3 percent. The resultant variation in percent relative humidity as read from the graph will be less than one unit of percent relative humidity, which is the limit of accuracy of the method.

One application of glycerol-water solutions for humidity control in corrosion studies is in connection with evaluation of volatile corrosion inhibitor papers. Glycerol-water solutions are used both for humidifying the test containers in the performance testing of these papers and in the evaluation of indicators for the inhibitor ability of the papers.

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Any discussions of this article not published above will appear in the June, 1958 issue

Corrosion and Protection of Galvanized Steel Transmission Tower Footings*

By J. D. PIPER

Introduction

SIX YEARS ago Piper and Piper¹ reported the results of an electropotential survey made on approximately 3000 steel towers to determine the condition of the galvanizing remaining on their footings. Most of the towers had been in service from 20 to 30 years in direct contact with the earth. Successive towers in the lines studied were metallogically connected together by an overhead ground wire, sometimes called a "skywire," fastened to the tops of the structures. At the ends of the lines this overhead wire also was connected to the station ground masses.

The criterion for protection was the potential of a tower with respect to a copper-copper sulfate half cell. Tower footings having potentials more negative than -0.85 volt were considered to be adequately protected by the galvanizing remaining on them. Tower footings having potentials less negative than -0.80 volt were judged to be inadequately protected. Examination of a few footings after unearthing substantiated the criteria selected.

The survey showed that approximately half of the 20 to 30 year old towers had potentials more negative than -0.85 volt to copper-copper sulfate. A few hundred had potentials less negative than -0.80 volt. Many of those were near power plants and switching stations. Temporary disconnection of the overhead ground wire from the stations caused the potentials of towers near them to become more negative to various degrees, indicative of the condition of the footings. At the time the paper was published an experimental installation of magnesium anodes had been made on parts of three lines from one switching station but little information was available on their effectiveness.

The present paper summarizes information obtained since the first paper was published. The object of the continued investigation was primarily to establish a long-time policy for protecting tower footings in the territory served by The Detroit Edison Company. The information is believed to be useful to others, particularly to those having towers in similar soils.

Protective Measures

From the information obtained in the survey previously reported, the obvious first step in protecting galvanized tower footings from corrosion was to separate



About the Author

JOHN D. PIPER is Division Supervisor of the Chemical and Metallurgical Division, The Detroit Edison Company, Engineering Laboratory and Research Department, Detroit, Michigan. His major fields of research include spectra of dyes, chemical constituents responsible for increased conductivity of liquid dielectrics and losses in oil-paper insulation, moisture equilibria in fibrous materials, detection and control of corrosion of the footings of galvanized steel transmission towers, and nature and control of deposits on the fire side of steam generators. Dr. Piper has an AB degree from Michigan State Normal College and MSc and PhD degrees from Ohio State University.

the metallic connection between the towers and the station ground masses or other structures of significantly more electro-positive nature. The problem of finding a means for effecting the separation in the overhead ground wire, without destroying its safety functions associated with lightning surges and fault currents, was referred to electrical designers in the authors' company who produced the device shown in Figure 1. The device consists of a strain insulator equipped with arcing horns. This insulator was placed in the overhead ground wires, usually between stations and strings of towers leading from these stations.

The second step in protecting the tower footings was to install magnesium anodes at towers having potentials more positive than -0.80 volt to Cu-CuSO₄. For the lower resistivity soils, 17-lb bagged anodes were installed in the center of the tower base and the lead wire was laid in a shallow trench and "Cadwelded" to a tower leg. For the experimental installation the bags were installed to a depth of 6 feet by hand digging. For the approximately 400 bag anodes since installed, a power digger was used to drill from the surface at one side of the tower to the center of the base at a depth of 8 feet. For the higher resistivity soils a 1-inch magnesium rod 10 feet long was driven 1 foot from each of the four legs. Leads from the four anodes were attached to the respective legs. Potentials of the towers to which both kinds of anodes were attached were determined approximately

Abstract

Galvanized steel transmission tower footings in direct contact with most aerated native soils in southeastern Michigan have practically indefinite lives if not connected to electropositive structures such as switching station ground masses. The galvanizing in these soils forms over its surface a dense, superficial, protective coating. The resulting electropotential of the footing may be as much as 0.3 volt more electropositive than a fresh zinc surface. Mild corrosion occurs at and below the water table on towers having part of their footings in "permanent" moisture. Serious corrosion has been found only on footings that have been metallogically connected to electropositive structures or that have been in direct contact with cinders and other coal products.

The condition of tower footings may be predicted with fair accuracy by means of electropotential measurements. The measured potentials vary with seasonal change, being lowest after prolonged dry weather.

Magnesium anodes furnish adequate protection for galvanized tower footings if protection is applied before the corroded area becomes too extensive. Need for an electropotential survey at approximately 10-year intervals is indicated.

7.7

a year after installation as a measure of the protection afforded, as will be discussed later.

Seasonal Change in Potentials

At the time the previous paper was written some fluctuation of potential with time had been observed. Some of the fluctuations occurred irregularly over the course of minutes. The numbers of towers thus involved were few and consequently the fluctuations were of minor significance. Usually those towers were in regions where stray currents were probable; a few exceptions were previously reported. More important from a practical standpoint were fluctuations that appeared to be related to the seasons at which measurements were made. Before a long-term policy for protecting towers could be established it was necessary to determine the significance of the seasonal change in interpreting the results of potential measurements.

To study the effect of seasonal change, 15 segments of lines, consisting of a few towers in each, were selected in different parts of the system. The potentials of the towers to the reference electrode, usually placed 10 feet away from one of the tower legs, and the soil resistivities, were determined several times a year. Soon it became apparent that the number of segments could safely be reduced to four, each representative of a particular condition. Table 1 describes the four segments, a total of 23 towers.

Figure 2 shows the potential changes of four of the towers from Segment 3; the data for the remaining four towers from that segment and the eight for

*Submitted for publication May 15, 1957. A paper presented at a meeting of the North Central Region, National Association of Corrosion Engineers, Detroit, Michigan, November 15-16, 1956. Paper originally was presented under the title "Corrosion in Power Distribution Systems Below Ground."



Figure 1—Insulator equipped with arcing horns.

Segment 1 were all similar. In January of 1951, when the only January set of data was taken, the potentials were nearly 0.9 volt as shown. By October of that year the potentials had fallen to 0.8 volt. Each succeeding year, for the four years the periodic tests were made, the potentials rose from fall to spring and dropped from spring to fall as Figure 2 illustrates. Superimposed upon the periodic rise and fall was a steady drop from 1951 through 1953 followed by a partial recovery in 1954. The data for Segment 2, the four old towers having "acceptable" potentials, were also similar except that the minimum potentials reached were not so low as for the 16 towers in Segments 1 and 3.

Figure 3 shows the data for the three new towers of Segment 4. From the time of the first measurements, made approximately a year after the towers were installed in 1948, to the fall of 1953 the potentials had dropped approximately 0.15 volt as shown. For the new towers as well as the old ones the drop was marked between spring and fall. The potential survey of the four segments thus established that the seasonal change in potential, instead of being a phenomenon peculiar to a few towers, is a more or less regular phenomenon to be reckoned with in establishing a criterion for protection in southeastern Michigan.

The reason the potentials change with seasonal change is only partially known. The effect of temperature differential between tower leg and reference electrode does not account for the variation. For example, consider a hot summer day, air temperature 35 C, ground temperature at depth 6 feet, 18 C. According to Ewing² a temperature differential of 17 C between two saturated copper-copper sulfate half cells would produce a potential difference of approximately 0.013 volt with the half cell at the higher temperature the more positive. Thus if the cycles were caused by unequal temperature between tower and reference electrode, the measured potential difference between the tower and reference electrode should be greater in summer than in winter. The converse is true, however, as Figures 2 and 3 show. The potential difference between zinc and copper half cells, both at the same temperature, does diminish as the temperature increases but the change, 0.000034 volt per degree, is negligible.

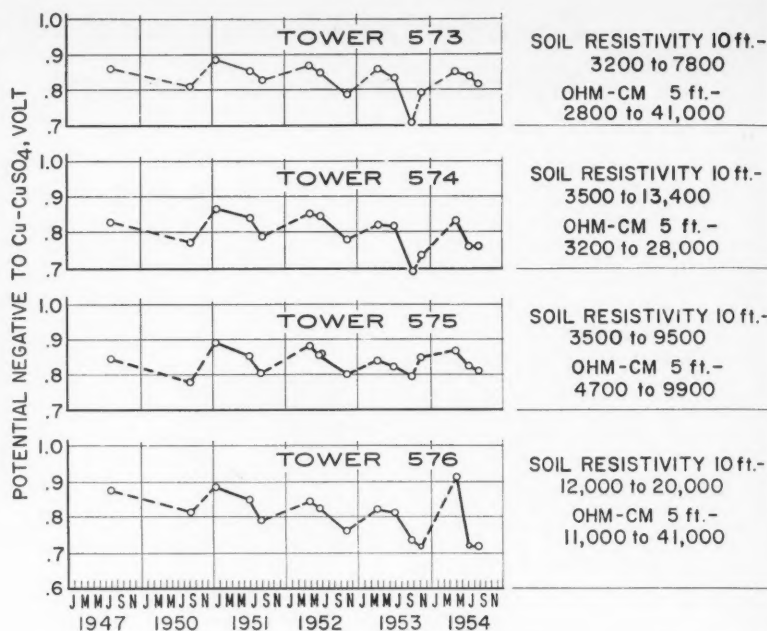


Figure 2—Potential changes of four towers representing old towers having medium low potentials.

TABLE 1—Description of Four Segments of Lines Selected for Determining Effect of Seasonal Change on Tower Potentials

Segment No.	Number of Connected* Towers in Segment	Kind of Condition Represented	Soil Conditions
1	8 (Includes Tower 1766)	Old towers showing large changes in potentials**	Old lake bottom; sand ridges having soil resistivities up to 180,000 ohm-cm over clay having resistivity between 1300 and 3000 ohm-cm.
2	4	Old towers having "acceptable" potentials**	Clay farm land, soil resistivity: average to 10 feet—2800 to 6300 ohm-cm; average to 5 feet—3000 to 10,000 ohm-cm.
3	8 (Towers 573 to 580)	Old towers having medium low potentials**	Hilly, one end in cat-tail swamp (see Figure 2.)
4	3	New towers	Hilly, well drained soil (see Figure 3)

* The towers in each segment were connected together and to adjacent ones by an overhead ground wire. All were remote from switching stations.

** As judged by three sets of measurements made between 1947 and early 1951.

The cyclic potential change probably is related to the change in moisture content of the soil in contact with the tower legs. An effort was made to use soil resistivity measurements as an indication of the moisture content of the soil. The measurements were made using the conventional four-pole method at spacings of 5 and 10 feet to give "average" resistivities to the 5 and 10-foot levels respectively.

The results of the tests confirmed what already was suspected (i.e., that the soil resistivities were the highest in the fall when the potentials were lowest.) Correlation between soil resistivity and potential was, however, very poor, even for a single location. The effect of soil moisture on tower potential is better shown by comparing the results shown in Figures 2 and 3 with the rainfall data given in Table 2. The low potentials for 1953 probably resulted from two successive years of abnormally dry weather. The partial recovery during 1954 (Figure 2) correlates with the nearly normal precipitation that year.

Potentials vs Condition Upon Unearthing

In establishing a criterion by which the probable conditions of tower footings can be predicted, it was necessary to differentiate between towers that had been connected by a relatively short metallic connection to more electropositive structures, particularly station ground masses, and towers too remote for the connection to have been of significance. Of the four unearthed tower legs described in Table 1 of the earlier paper¹ the two on which bare steel had been found were located near to and metallically connected to stations. The other two towers, on which the galvanizing had been intact, were miles from any station. Further unearthings have since been made, some on towers remote from stations, others on towers located more closely in.

The method used for examining the unearthed legs was to scrub off the earth and reasonably loose corrosion products, wipe dry, and examine both visually and with the cell shown in Figure 4. To use the cell, the cotton wick,

wet with zinc and iron sulfates, was touched to any suspicious-looking spots after they had been polished to bare metal with coarse metallographic paper. The potentials were then determined. It was soon learned that potential values obtained on unpolished surfaces were much lower than those obtained on polished surfaces and gave little indication of the protection still afforded by the galvanizing.

Five of the towers selected for unearthing to represent those remote from stations were a part of the segments described in Table 1. The electrical behaviors of Towers 573, 574, and 575, from Segment 3, have been shown in Figure 2. Observe that the measured potentials of Tower 574 were consistently a few hundredths of a volt lower than those of the rest of the group. The potentials of Tower 577, on the other hand, were slightly higher than those of any of the four represented in the figure. The average potentials of Tower 766 were the lowest of the eight towers in Segment 1. Following is a summary of the conditions found at each of these towers, September 1954.

Tower 573. Location: in cat-tail swamp; humus to 6 inches, wet sand to 6 feet, wet, sandy clay beneath, pH 6 to 7. Unearthed leg and anchor were covered by hard crust of strongly adherent corrosion product. Mechanical removal showed all galvanizing intact, with spot-cell potentials in excess of 1.0 volt.

Tower 574. Location: in field at edge of swamp; dry sand loam to 5½ feet. Below 6½ feet the soil was wet and contained considerable clay. Entire leg was covered by firmly adherent deposit, galvanizing beneath intact giving spot-cell potentials in excess of 1.0 volt. Galvanizing on anchor at base of leg was dissipated in spots along edges of both the angle and the channel members. Typical potentials at 2½ inch steps along one of the angle members were as follows: 1.0, 1.0, 0.63, 0.72, 0.93, 0.48, 0.90, 0.90, 0.86, 0.97, 0.60, 0.72, 0.85 and 0.88.

Tower 575. Location: in well drained soil on long slope. At 2½ feet, there was sandy clay, and pH was 6.2. Other conditions were as follows: 4 feet, clay; 7 feet, clay, pH 6.3; anchor, wet clay, pH 6.8. Galvanizing was intact on leg and anchor and all potentials were in excess of 1.0 volt.

Tower 577. Location: near top of slope. Soil conditions were as follows: at 1 foot, sandy loam, pH 7.0; 3 feet, sandy loam, pH 6.8; 7 feet, sandy clay, pH 7.2; anchor, wet clay, pH 7.2. Galvanizing was intact on leg and anchor, and all potentials were in excess of 1.0 volt.

Tower 1766. Water table, usually near surface, was at 5-foot level when tower footing was examined in September of 1954. Humus was at surface, layer of clay extended to 2-foot level and then a layer of sand to 3½ foot level. Below 5 feet there was wet clay. Galvanizing on leg and anchor was covered by a hard crust; galvanizing beneath was intact giving potentials in excess of 1.0 volt.

Inasmuch as only one of the five unearthed tower legs showed any breakthrough in the galvanizing, and that occurring on the one showing the lowest potential in the field survey, it seemed improbable that any exposed steel would be found on any of the rest of the

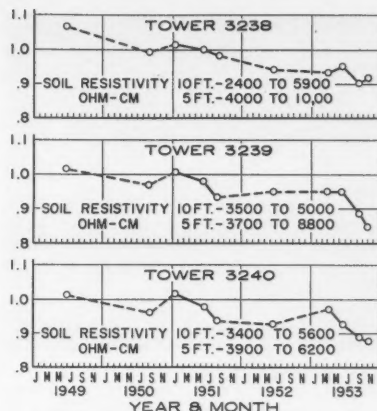


Figure 3—Potential changes of three new towers.

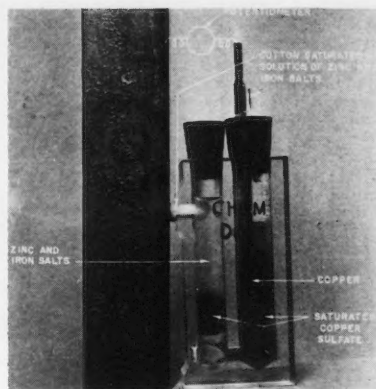


Figure 4—Spot cell for examining tower legs.



Figure 5—Extensively corroded leg of Tower 2400.

TABLE 2—Rainfall in Detroit Area*

YEAR	Inches of Rainfall
1950.....	39.46
1951.....	37.78
1952.....	29.34
1953.....	23.86
1954.....	33.49

* From U.S. Weather Bureau.

towers that had been subjected to the periodic measurements. In a further effort to locate a remote tower where the galvanizing had dissipated through to the steel, a tower was selected for unearthing which in the original survey had a potential less than 0.8 volt and which had been protected since by a magnesium anode. Pertinent information is as follows:

Tower 847: Potentials before anode installations were 0.721 volt in August, 1947, and 0.753 in August, 1950. Potentials after anode installation in the summer of 1951 on this and connected towers were 0.880 in July, 1952 and 1.02 in September, 1954. Upon unearthing September, 1954 soil conditions were as follows: surface, clay loam; clay below plow furrow, pH 6.7. Soil resistivity, average to 5 feet, 5000 ohm-cm; average to 10 feet, 2400 ohm-cm. Patches of corroded-through galvanizing were found between 3 foot and 5½-foot level, the balance was intact.

As the result of line changes a leg of one other remote tower had previously been examined in 1953. Following is a summary of conditions:

Tower 2534: Potential in August, 1948 was 0.861 volt. Crust was over galvanizing giving a potential of 0.8 volt at 5½ foot level. After cleaning to bare metal at the apex of the angle-shaped leg, potentials at ten 1-ft. intervals were 1.06 to 1.08 volts except at two mechanical gouge marks where potentials were 0.81 and 0.70 volt.



Figure 6—Fifty-mil deep pit in leg to Tower 2400.

One or more legs of the following towers that at one time were grounded to station ground masses have also been examined:

Tower 2400: Installed new in 1948, attached to two overhead ground wires, one connected to station and the other to Tower 2401. Tower 2401 was attached also to two other overhead ground wires, one to station, and the other to the first of a long string of old towers having potentials ranging between 0.67 and 0.80 volt for approximately three miles. When first tested in 1950, potential of Tower 2400 was

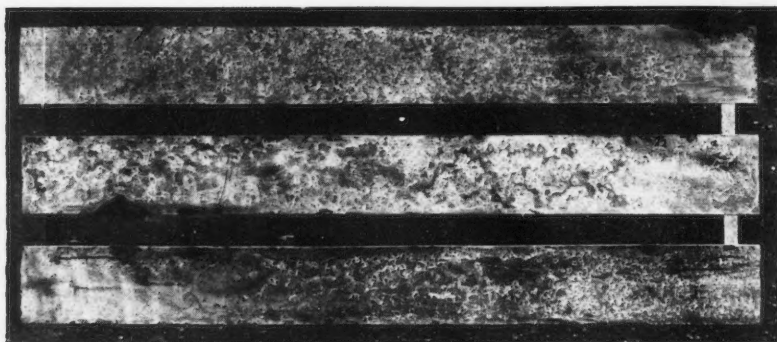


Figure 7—Corrosion on anchor of Tower 2400.

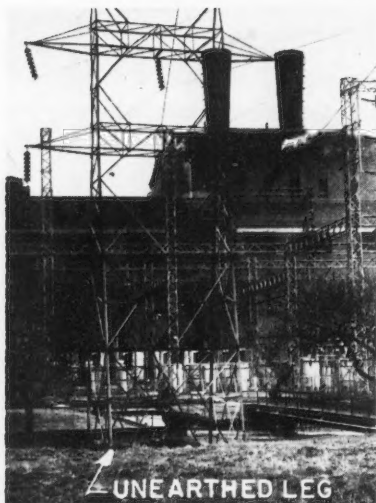


Figure 8—Location of tie line tower with respect to station and overflow canal.

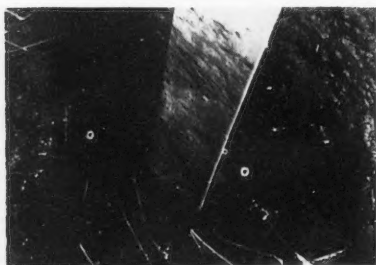


Figure 9—Extensive corrosion on leg in fill soil containing cinders. Tower was bonded to buried bare copper cables.

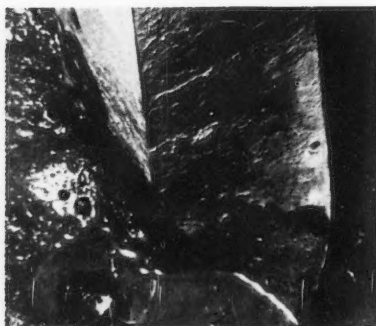


Figure 10—Intensive corrosion at water line on leg in clay. Tower was bonded to buried bare copper cables.

0.66 volt negative to a copper-copper sulfate electrode placed near it; resistance to station was 0.1 ohm. In 1951, insulators (Figure 1) were placed in the two ground wires between the station and Towers 2400 and 2401. In September, 1951 potential of Tower 2400 was +0.27 volt to station, and -0.38 volt to reference cell in "remote" earth. A current of 0.75 ampere was required to bring tower potential to -0.85 volt. An insulator was then placed in ground between Towers 2400 and 2401 to protect anodes that had been installed on the line; insulator to station was shunted until 1954. In July of 1954, Tower 2400 again was isolated and found to be 0.11 volt positive to station. Individual legs were unfastened one at a time; three were found to be negative to station and the fourth was positive. Positive leg was unearthed. Porous fill soil was found and there were some cinders. Bottom of hole was electropositive to top by as much as 0.24 volt; there were no foreign metallic structures in hole. Galvanizing was extensively dissipated from leg (see Figure 5). Some pits were found in steel (the deepest is shown in Figure 6). Galvanizing on anchor was moderately dissipated as shown in Figure 7. Leg was shortened and leg and anchor restored and encased in concrete. The other three legs were excavated a few feet to permanent moisture through fill containing some cinders, then were covered by crushed limestone and protected by a magnesium anode. Insulator between Towers 2400 and 2401 was removed. Potential of Tower 2400 was -0.385 volt to station and -0.945 volt to reference electrode in "remote" earth.

Towers Connecting Two Parts of a Station: In 1949, nine towers having galvanized-steel footings had been used to join the original switching station at one of the power plants to an addition. The overhead ground wire from most of these towers had been connected directly to one or both parts of the station. In addition, at least two legs, and usually all four, had been connected to grounding straps attached to heavy bare copper cables that are buried in the earth and connect the two parts of the station.

In 1953 one of the nine towers was temporarily isolated from its several grounds and its potential determined to be -0.17 volt to the station ground, which was approximately -0.73 volt to copper-copper sulfate in remote earth. To determine the condition of the galvanizing on the footings, one of the legs was unearthed.

Figure 8 shows the location of the tower with respect to the older part of the station and an overflow canal. The soil was clay. Potentials of the leg at spots polished to bare metal ranged from -0.92 to -0.97 from the surface down to four feet below. At the 5-foot level, which was approximately the level of the water in the canal, the potentials ranged from -0.64 to -0.75 volt. A few square inches of bare steel were found. The towers have since been isolated from the station ground mass, but left metallically connected one to each other, and have been protected by magnesium anodes.

Four legs of one tower and one on another of the nine were examined in 1956 after the isolation had been completed. All the legs examined showed considerable damage to the galvanizing. The most extensive damage (illustrated in Figure 9) was found on legs that were in fill soil containing considerable cinders. Pits in the steel ranged up to 15 mils deep. The most intensive damage was found, however, on a leg that had been in contact not with cinders but with clay. On that leg the galvanizing was intact to within a few inches of the water table. There, as shown in Figure 10, the corrosion was severe. As a matter of fact pits up to 50 mils deep were found where the leg curved to join the anchor which had been encased in concrete.

Tower 944. For 23 years this tower was the fifth out from a switching station, as shown in Figure 11, and the second tower from a concrete-based pole grounded by copper-weld rods. The potentials were the most electronegative of the group both when tested originally while ground wire was attached to station and after wire was temporarily disconnected (see Figure 11). Line was changed before readings were made in 1950. Long string of new (F) towers, attached in place of the string of old (A) towers, plus insulator placed in overhead ground at station, resulted in the much more negative potentials shown. Further changes resulted in abandonment of tower and availability of leg for inspection. Figure 12 shows ground water level and potentials when the leg was uncovered for inspection. Bare steel found in a few spots between the 6 and 7-foot level.

Table 3 summarizes the correlation between the potential readings and the condition of the galvanizing for all the unearthed towers that had been metallically connected to the station ground mass. Every one of such towers examined having potentials of 0.83 volt or less, negative to copper-copper sulfate, has been found to have had at least some bare steel on its footings. Particular attention is called to the first four towers listed in the table. Within six years from the time they were installed new, the galvanizing on their footings had become dissipated to a serious degree. Each had been metallically connected to the station ground mass, some through bare copper wires buried in the soil. Much slower was the corrosion rate of the three towers listed at the bottom of the table, which although metallically connected to the station's ground mass, were connected through a wire attached to intervening towers.

Examination of the unearthed tower legs substantiated the observation that towers remote from stations and not

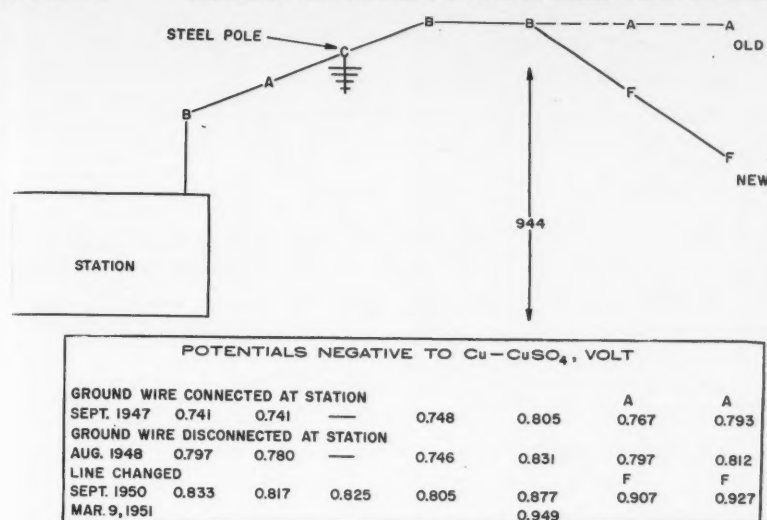


Figure 11—Potentials of Tower 944 and adjacent towers before and after disconnection of ground wire to station.

metallically connected to other electro-positive structures behave quite differently from those so connected. In the territory where the investigation was carried out, new galvanized tower legs not connected to other structures give a potential of approximately 1.1 volt negative to a copper-copper sulfate cell. With time the galvanizing tends to form over its surface a protective corrosion product. In well drained and presumably aerated soils this corrosion product is very dense and adherent and results in potentials much less negative than those given by new zinc. The galvanizing on towers in such soils gives practically indefinite protection for the steel contacting it. The protection is largely mechanical; it is improbable that this galvanizing could protect galvanically any bare steel on parts of the footing a few feet distant.

The superficial corrosion product on any part of a footing that is below the "permanent" water table seems to be less impervious than that in aerated soils with the result that the galvanizing beneath retains part of its electrochemical action. The most severe corrosion has been found at the level of the meandering water table, which for many of the clay soils in the territory is from

3 to 8 feet below surface. The measured potentials of towers probably reflect the electrochemical behavior of the parts in contact with the more moist soil. A change in the level of the water table therefore will affect markedly the potentials of towers having footings that pass through that table.

Towers that are connected to station ground masses or other electropositive structures corrode primarily as a result of the galvanic couple so established. The corrosion takes place principally at parts exposed to permanent moisture. The corrosion product so formed appears to be much less firmly attached and more permeable than that on the remote towers, even on those parts in permanent moisture.

It is not inferred that metallic attachment to the station ground mass is the only factor involved in the corrosion of towers near stations. In the case of two of the four towers listed on the top of Table 3, the nature of the fill soil was involved; cinders were in the fill over part of the length of the leg of Tower 2400 and over two of the three examined legs of the tie tower, I. Laboratory tests have shown that even cinders leached to the point of neutrality have an adverse effect on galvaniz-

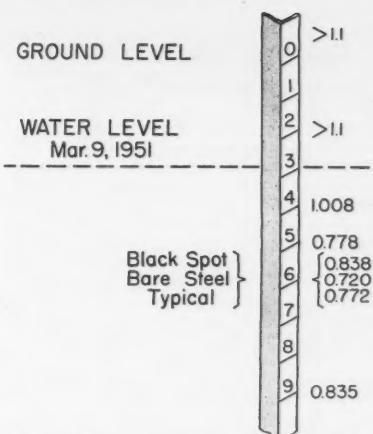


Figure 12—Spot cell potentials of unearthen leg of Tower 944.



Figure 13—Drastic corrosion caused by coal mill refuse.

ing because chunks of coke in contact with galvanizing form not only strong cathodes but also low resistivity external circuits for galvanic cells.

Figure 13 shows the drastic effect caused by acidic coal products, in this case coal mill refuse inadvertently bulldozed around a leg of a tower set in a porous fill. The tower involved was adjacent to a power plant but was not connected to it metallically. The fill in the vicinity of the corrosion had pH values ranging from 2.1 to 7.5.

Another possible difference between the four towers listed at the top of Table 3 and the other 10 unearthened is the thickness of the galvanizing origi-

TABLE 3—Condition of Footings of Towers Attached to Station Ground Mass

Tower Designations	Time Grounded to Station Ground Mass, Years	Number of Towers Between Tower Examined and Station	Potential Negative to Cu-CuSO ₄ , (Volt.) when Ground to Station		Condition
			Connected	Disconnected	
2400	6	0	0.66	0.38	Galvanizing on one leg all nearly gone below 3-ft. level; steel pitted.
Station Ties	4	0*	0.56	0.73	Some bared steel at and below 5-ft. level, slight wasting of steel.
I	6	0*	0.58	Companion Tower A	
H	6	1*	0.58	**	Below normal ground-water level 5 feet from surface galvanizing gone from approximately three-fourths of surface.
903***	24	5	0.72	0.79	Practically no galvanizing remaining on two legs in fill soil containing cinders; galvanizing intact on leg in clay down to ground-water level where corrosion severe.
880***	24	3	0.72	0.81	Beginning 4½ feet below surface bare steel exposed on half of surface.
					Below 4-ft. level only alloy layer remaining from the galvanizing and that perforated especially between 6 and 8-ft. level exposing a few square inches of steel.
944	23	4	0.80	0.83	Bare steel in a few small spots between 6 and 7-ft. level.

* Two or more legs attached not only to overhead ground wire but also to bare copper cables buried in earth and attached to station ground mass.

** After all intentional grounds removed the nine towers were still grounded to station by water pipe passing through base of H. Galvanic anodes on the system when that ground was broken.

*** See Reference 1.

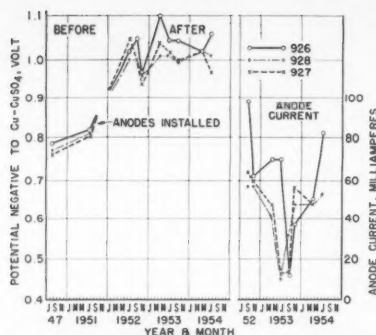


Figure 14—Typical behavior of bagged anodes attached to towers on clay soil.

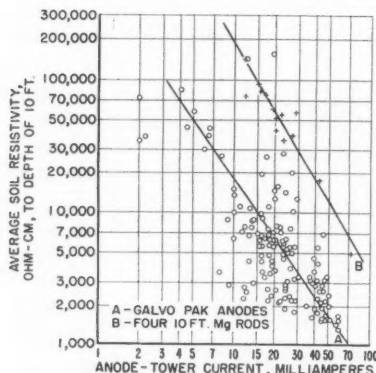


Figure 16—Soil resistivity versus internal resistance of the cell, anode to soil to tower.

TABLE 4—Potentials of Steel Rods

Material	Potential Negative to Cu-CuSO ₄		
	6-18-55	8-6-55	8-25-55
Carbon Steel (1).....	0.77	0.77	0.78
Carbon Steel (2).....	0.79	0.78	0.77
Corten Steel (1).....	0.77	0.80	0.79
Corten Steel (2).....	0.80	0.79	0.81
Toncan Steel (1).....	0.76	0.77	0.74
Toncan Steel (2).....	0.75	0.72	0.69

nally on the members. The four that deteriorated so rapidly probably were manufactured in the 1940's; the other 10 in the 1920's. The older towers probably had at least 3.4 oz of zinc per square foot on their legs because that much was found at and above grade level on the smaller brace members described by Kerstein and Gibson³ after 35 sampled towers had been in service between 15 and 21 years. How much zinc was originally on the legs of the four towers made in the 40's is unknown; specification required no less than 2 oz per square foot. Jacobi⁴, for example, believes that present day galvanizing is less effective than it was years ago. No data are available from the present investigation either to support or to refute that opinion.

Criterion for Protection

Are potential measurements of any value as a criterion of the condition of the galvanizing on tower footings when the values fluctuate with seasonal change? If so, what value should be

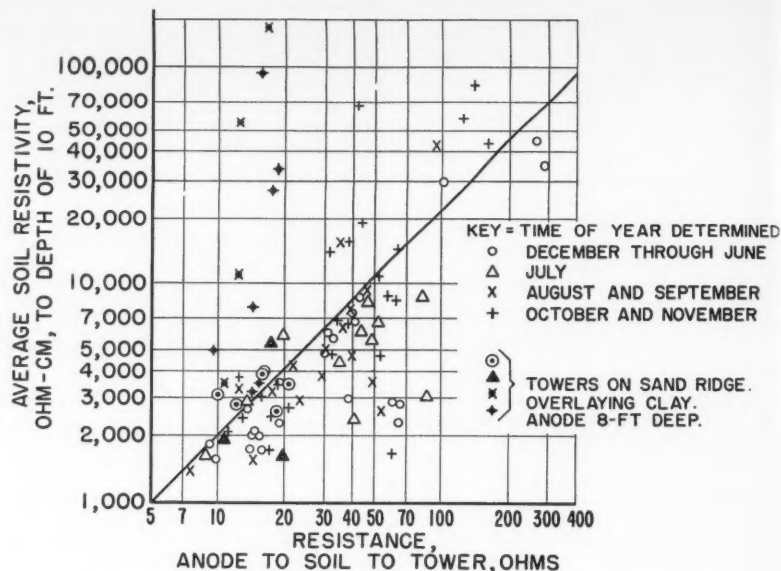


Figure 15—Effect of soil resistivity on current output of anodes attached to towers.

used as the criterion of protection? For the territory covered by this investigation, where the soil ranges from clay to sand, has a pH 6 to 9, and is fairly moist during most of the year, the potentials are of value as a criterion. For remote towers a criterion has been empirically established as follows:

- (1) Potentials of towers where galvanizing was found to be just breaking through to bare steel were, 0.85 from January through June, dropping to 0.75 by the last of August, to 0.72 in October.
- (2) Lowest potentials found on towers having no breaks in galvanizing were approximately 0.9 from January through June, dropping to 0.8 by the last of August and to slightly lower than 0.8 in October.
- (3) Potentials of bare steel rods driven in clay soil usually were slightly below 0.8 volt (Table 4); top of rods was 5 feet below surface and bottom 10 to 12 feet below surface.

All three methods of establishing a criterion show that potential readings are approximately 0.8 volt.

In establishing the criterion it was necessary to define the time of year. The most consistent potentials are found during the first six months of the year when the soil is usually wet. Because of cold weather and high water the making of measurements during the first four months is impractical. The most practical time for the author's company is during July and August while student help is available. That is just the period when the potentials are changing the fastest. Present practice is to use a criterion of 0.80 volt as of August 1, equivalent to 0.82 volt on July 1 and 0.78 volt on September 1. The making of routine measurements after September 1 is avoided; furthermore, all towers showing low potentials are retested at a different time of the year.

For towers that had been connected to station grounds or other electropositive structures the criterion of 0.85 volt, previously established (1), was retained.

Effectiveness of Magnesium Anodes Used to Protect Tower Footings

The effectiveness of magnesium anodes in protecting tower footings from corrosion can be evaluated at this time only by the potentials of the towers with respect to a reference electrode. Figure 14 gives a typical example of the change in tower potential resulting from the attachment of 17-lb bagged anodes to each individual of a series of towers in clay soil. The three towers there represented constituted one of several groups periodically tested before and after the anodes were installed. The outputs of the anodes at the three towers are also shown. During the extremely dry weather of 1953 the anode current dropped to low values; potentials, however, did not drop abnormally. As was the case for towers not so equipped, potentials of towers equipped with anodes fluctuated with seasonal change.

The respective resistivities of the soil in the vicinity of each of the three towers were in ohm-cm, average to a depth of 10 feet: Tower 926, 1440 to 2110; Tower 927, 1760 to 2780; Tower 928, 1740 to 4420. For most of the approximately 400 anode installations made to the present time, a single potential measurement has been made approximately a year after installation instead of the series represented by the figure. In general the potential changes were similar to those shown in the figure.

As Figure 14 further shows, many of the towers to which the anodes were attached were brought to potentials more negative than necessary. In many cases attachment of anodes to only half the towers provided adequately negative potentials to segments of lines. Attachment of anodes to single towers showing low potentials was not usually effective when those towers were connected to the ground wire attached to adjacent towers, having potentials nearly as low. Evidently the output of a single anode was insufficient to cause a significant change.

Anode Output in Soils of Different Resistivities

Figure 15 shows the relationship between soil resistivity and the output of both the bag-type anodes and the magnesium rods. The data for the bag-type anodes were taken from a plot of 23 experimental anodes set to a depth of 6 feet. The data for the rods were taken from four separate installations where 10-foot rods were driven a foot away from each of the four tower legs. Both sets of data were taken at various times of the year between 1949 and 1953. As the figure shows, for given current output the rods may be used in soils having six to ten times the resistivities of those in which the bagged anodes are used. Single soil resistivity tests, however, leave much to be desired in predicting anode behavior.

The current outputs shown in Figure 16 are dependent upon the potential difference between anode and tower as well as the resistance of the circuit. In Figure 16 the variable of nonuniform potential difference is eliminated; the figure shows the measured soil resistivities plotted against the corresponding internal resistances of the cell, anode-to-soil-to-tower. The data are coded to designate the time of year when the measurements were made. They include the data for two installations where the anodes were installed to a depth of 8 feet. For one of these two the data were similar to those from the 6-foot installations. The data for the other installations are separately coded as shown; they refer to a group of towers on a sand ridge overlaying clay. Although the soil resistivity for that group changed markedly with seasonal change, the internal resistance remained reasonably constant.

The straight line appearing in Figure 16 is a reproduction, and extrapolation to higher resistivities, of a figure in *Anode*⁵ showing the anode to earth resistances of "Galvo-Pak" anodes. The line agrees with the data about as well as any line could. Figure 16, like Figure 15, shows the wide spread between the predictions that may be made on the basis of soil resistivity measurements and the actual behavior of anodes in the territory where the investigation was carried out. As is illustrated in the extreme case shown by the towers on the sand ridge, the anodes were much more nearly constant in their behavior with seasonal change than were the results of soil resistivity tests.

Limits on Corrosion Control of Tower Footings To Be Expected of Magnesium Anodes

The study reported in this and the previous paper¹ has shown that galvanized steel tower footings set in most native Michigan soils have very long lives if not connected metallically to more electropositive structures. Where corrosion has occurred, attachment of magnesium anodes, usually one to a tower, has provided ample protection. This paper does not infer, however, either that galvanized steel footings will fare so well in all soils or that attachment of magnesium anodes will solve all corrosion problems.

The underground area of most of the towers involved in the survey ranged from 160 to 360 square feet. If all the steel were bare and exposed to native soil even the smaller towers would require perhaps 150 ma to bring their potentials to -0.85 volt. The requirements might be even greater under adverse conditions; for example, Tower 2400 required 750 ma to bring its potential to -0.85 volt although most of the corrosion was confined to a single leg having an area considerably less than 100 square feet. The reason that a single bagged anode per tower usually has proved to be more than ample is that only a small proportion of the total area needs protection other than that being given by the residual galvanizing. Should towers be allowed to corrode to the extent that a large proportion of the surface were bare steel before protection was applied, use of magnesium anodes might prove to be impractical or ineffectual.

Present plans call for (a) an electropotential survey of existing lines at 10-year intervals with more frequent survey of parts of lines that are in fill soil or that were at one time connected to electropositive structures, and (b) vigilance in erecting new towers to avoid corrosive fill and undesirable connections. For locations where metallic connection to electropositive structures or corrosive fill is unavoidable, provision is made either to avoid the use of galvanized footings or to cover them with concrete.

Summary

(1) Galvanized steel transmission tower footings in direct contact with most aerated native soils in southeastern Michigan have practically indefinite lives if not connected to electropositive

structures such as switching station ground masses. Under these conditions the galvanizing forms a dense protective coating over its surface resulting in electropotentials up to 0.3 volt more electropositive than new zinc.

(2) Mild corrosion occurs at and below the water table on towers having part of their footings in "permanent" moisture; even at these locations the life of the galvanizing is approximately 25 years for tower legs originally having approximately 3.4 ounces of zinc per square foot of surface.

(3) Serious corrosion may occur on footings that have been either metallically connected to electropositive structures or in direct contact with cinders or other coal products.

(4) Electropotential measurements provide a fairly accurate means of predicting the condition of tower footings. The measured potentials change with seasonal change, however, and hence must be interpreted accordingly.

(5) For typical Michigan soils a potential of 0.80 volt negative to copper-copper sulfate indicates that the footings are still being protected by the remnant of the galvanizing upon them; for abnormal regions a value of -0.85 volt is suggested.

(6) Magnesium anodes furnished adequate protection for galvanized tower footings if protection is applied before the corroded area becomes too extensive and if the towers are not metallically connected to electropositive structures.

Acknowledgment

The author is pleased to acknowledge the cooperation of many colleagues in making this investigation possible. Particular recognition is given to M. F. Wider, Supervisor, Mechanical Section, Overhead Lines Department; R. H. Mertz, Electrical Apparatus Engineer, Electrical System; H. R. Harris, Electrical Engineer of Power Plants, and T. A. Alessi, Engineering Laboratory and Research Department.

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Any discussions of this article not published above
will appear in the June, 1958 issue

The Use of Magnesium for the External Cathodic Protection of Marine Vessels*

By C. F. SCHRIEBER

Introduction

THE USE of cathodic protection to control corrosion of marine vessels has been a development of considerable interest to the marine industry. In recent years there has been a rapid and successful expansion in the scope of this application, resulting in many new developments.

It will be the object of this paper to summarize the information and experience gained through the experimental use of magnesium anodes to control the corrosion of marine vessels. The paper will cover, briefly, the electrochemical nature of corrosion and the problems which confront both the ship operator and the corrosion investigator. A review of Dow's experiences with marine vessels ranging from small boats and barges through ocean-going ships will be presented. Anode design, application technique, and pertinent economics will be included.

Nature of Hull Corrosion

The nature of hull corrosion will vary with both environment and location on the hull. Corrosion occurs as a result of an electrical current which flows between local anodic and cathodic areas of the hull (as shown in Figure 1). As a result of this current, metallic ions pass into solution at the anodic area, while hydrogen ions are released at the cathodic area. Loss of metal at the small anodic area results in localized pitting. The elimination of local action cells is of vital importance, and a knowledge of what causes the formation of these regions often suggests a remedy. The following paragraphs outline the primary areas of corrosion activity on marine hulls.

1. Bare steel and painted steel exhibit different potentials. This difference is a cause of corrosion, with the painted steel normally demonstrating cathodic properties¹. Irregularities, such as mill scale, are cathodic to the steel surface, and also cause highly active local corrosion².

2. Steel exposed to the prevailing aerated water at the bow becomes the cathode of an intense oxygen concentration cell, with the corroding anodic areas being the steel in the deeper, less aerated waters. Furthermore, coating flaws resulting from anchor chain activity create additional anodic areas of corrosion.

3. Corrosion activity near the stern is caused by the dissimilar metal couple between the manganese bronze propeller and steel hull, plus excessive water

About
the
Author



C. F. SCHRIEBER, since 1953, has been connected with the Electrochemical Engineering Department of the Dow Chemical Company at Freeport, Texas. He now serves as Project Leader in charge of Electrochemical Applications. Mr. Schrieber attended Texas A and M, majoring in chemical engineering. Among other projects he has been actively engaged in corrosion control and cathodic protection since 1953.

turbulence in this area. Electrically bonding the propeller shaft to the hull will increase the attack on the hull, which becomes anodic to the bronze propeller. Extensive pitting then occurs at defects in the hull coating in close proximity to the stern frame and rudder assembly. However, electrical bonding of the shaft to the hull is not generally practiced. Under these conditions, electrical continuity exists between the dissimilar metals while the ship is inactive. Once underway, a heavy oil film usually insulates the propeller from the vessel proper and allows accelerated corrosion of the unprotected propeller.

4. Recent surveys of hulls in service from 1 to 16 years revealed aggressive early pitting in the vicinity of the stern frame and rudder assemblies, pitting in from 2 to 4 years at the bow, and in from 8 to 10 years at the midship area.

5. The nature of corrosion on small boats corresponds closely to the mechanisms previously described. Of importance on barges is the effect of intermittent wetting at the water line, this area being cathodic to steel permanently immersed.

Problems of Ship Operators and Corrosion Investigators

It would appear that the practice of allowing for general plate wastage in the construction of a ship hull would economically preclude cathodic protection. However, uniform hull corrosion is generally not the case localized pitting predominates.

It is difficult to fully establish costs of external hull corrosion, as they vary with the hull involved. Since corrosion

Abstract

Reports are made on the use of magnesium anodes for the external cathodic protection of marine vessels. Experimental studies over a 5-year interval reveal that the over-all hull, in addition to the much-discussed stern area, may be protected effectively by a distributed system of anodes. The variables of anode weight, optimum length and number of anode strings are related to a one or two-year anode life. Absence of marine fouling over the same period is discussed. Some consideration is given to economic matters. Cost data for cathodic protection of ships is given and compared with maintenance costs for unprotected ships. 8.9.5

costs are intangible, the ship operator is reluctant to spend money in addition to that presently being spent on preventative maintenance and corrosion damage repair. Therefore, the investigator considering cathodic protection is immediately presented with the problem of developing methods which do not greatly exceed existing maintenance costs.

Another problem confronting the investigator is to work out simple methods for determining the effectiveness of cathodic protection. One method involves the measurement of half-cell potentials of steel with respect to a suitable reference electrode. A value of 0.80-0.85 volt (Cu-CuSO₄) is considered satisfactory. Another method³, satisfactorily used to establish the effectiveness of cathodic protection, involves the measurement of rust tubercle pH. This technique allows pitting evaluations to be made immediately after dry docking, by using either a pH indicator paper or a portable pH meter fitted with a drop-size electrode. Corroding pits have pH values below 6.5-7.0, whereas inert, or cathodically protected pits, have values ranging from pH 7.0 to distinctly alkaline values.

Small Boats and Barges

The author's company entered the field of external hull protection in 1947, after concluding various studies on the performance of steel in sea water under the influence of cathodic protection^{4,5}. Initial experiments were conducted on several tugs, whose wetted surface areas approximated 2000 square feet.

One of the earliest installations con-

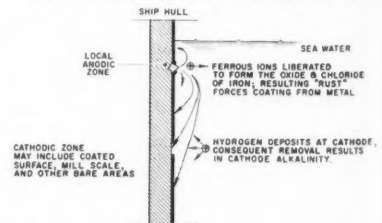


Figure 1—Cross section of a steel hull with active anodic pit and adjacent cathodic areas.

* Submitted for publication October 11, 1956. A paper presented at a meeting of the South Central Region, National Association of Corrosion Engineers, San Antonio, Texas, October 23-26, 1956.

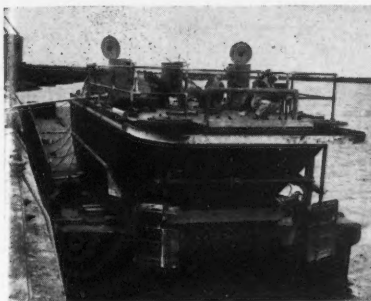


Figure 2—Installation of cylindrical anodes on the stern section of a small marine tractor.



Figure 3—Early installation of anodes on the forward rake of an unpainted steel barge.

sisted of suspending several 50-lb, cylindrical anodes between horizontal members of the after section on a marine tractor, the *Sea Mule*, as shown in Figure 2.

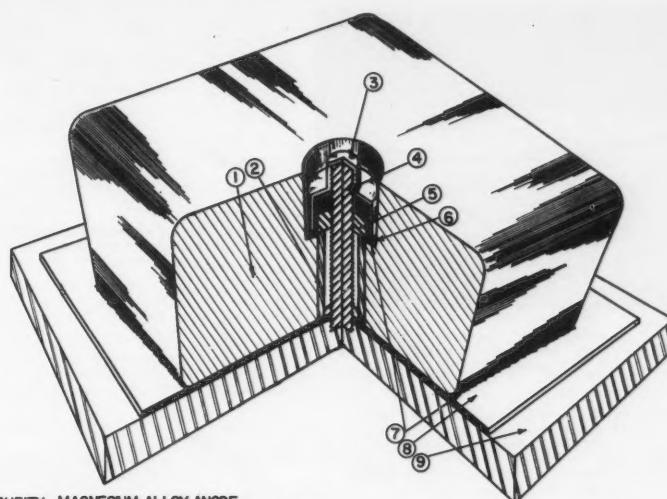
Shortly thereafter, several magnesium soil anodes were modified and secured to the stern counters of the tug *Edco*. This preliminary study disclosed hull potentials in the order of 1.2 volt (Cu-CuSO₄ reference electrode). Although excess current had been applied, the corrosion-free appearance of both hulls after periods of six and 12 months was striking. Calculations, based on magnesium consumption, placed the average current density at 9-12 ma/sq ft.

Shortly thereafter, several all-steel barges, with approximately 4000 square feet of wetted surface area were equipped with anodes on the rakes. This installation is shown in Figure 3. An appraisal of the barge installations disclosed satisfactory half-cell potentials and adequate protection at current densities of 5.6 ma/sq ft.

The general success of the foregoing studies, together with similar endeavors in the control of heat exchanger corrosion, led to the introduction of the compact magnesium anode shown in Figure 4. This anode is now used extensively on small and medium-sized tugs and barges.

Particularly interesting are the histories of the *Seal Mule* and the *Edco*, which have been completely protected since 1949. Maintenance coatings were deemed unnecessary, and have not been applied since 1949.

The company's success with the cathodic protection of smaller craft, supported by comparable successes by Canadian investigators on medium-sized vessels in 1950⁶, lent further stimulus to the expansion of the cathodic protection program.



1. 1/2" HIGH PURITY MAGNESIUM ALLOY ANODE
2. 2 1/8" x 3/4" PIPE CORE CAST IN CENTER
3. PLASTIC STUD PROTECTOR 1/2" APPROX. 8" x 8" x 4"
4. 1/2" STEEL STUD EXTENDING 3/5/16 ABOVE PROTECTED SURFACE
5. STEEL HEX NUT, 1/2"
6. RUBBER GASKET FOR PLASTIC STUD PROTECTOR
7. GASKET SEALER COMPOUND
8. 1/16" SHEET RUBBER 10 1/2" x 10 1/2" WITH 1/2" HOLE AT CENTER
9. PROTECTED SURFACE

Figure 4—Small boat anode installation (single stud).

SS Marine Chemist

In 1950-51, long-term testing began on the hull of the 12,500 ton tanker *SS Marine Chemist*. Four factors were of primary interest at that time:

1. Could the various mechanisms of corrosion be controlled?
2. Could a magnesium anode supply the necessary current for protection for a period of at least a year?
3. Could anodes be developed which would remain attached to the hull under velocity conditions?
4. Could anodes be attached to the hull without creating excessive drag?

The first anode used on ocean-going tankers weighed 60 lbs and was secured by two stainless steel stud bolts welded to the hull. Plastic caps, placed over the bolts, furnished an insulating barrier between the magnesium/steel core junction. A water-repelling grease and rubber gasket separated the hull from the underside of the anode.

The initial installation was completed in October, 1951, and consisted of 106 anodes, arrayed in groups of 53 anodes located port and starboard at the stern end of the roll keels.

At the end of one year, in 1952, inspection revealed:

1. Seventy-five to eighty-five percent of the submerged hull showed complete protection. Limited corrosion was noted in the vicinity of the stern frame and rudder assembly, and also in an area 150 feet aft the bow post.
2. Anode life was greater than one year.
3. Mechanical attachment of anodes was satisfactory.
4. Although the 60-lb anodes projected 8-9 inches from the hull, no retarding effect was noted on the speed of the vessel.

It was decided to re-install anodes in exactly the same manner for the following year, with the object being to extend

the area of polarization or polarization film with time.

Observations in 1953, following two years of cathodic protection, were:

1. Hull protection remained the same as it had been for the interval 1951-52, with no obvious extension of the polarization area.
2. Hull polarization alone is insufficient to prevent a large portion of the anode current from following the low resistance paths to the hull. As shown in Figure 5, this action resulted in excessive current densities in the vicinity of the anodes with a subsequent removal of the protective coating in that area.
3. The vessel was remarkably clean with respect to all marine fouling at both the 1952 and 1953 drydockings.

Calculations, based on magnesium consumption during the interval 1951-53, gave an average current density of 5.8 ma/sq ft during the first year and a value of 5.3 ma/sq ft for the second year. This deviated from the original design of 10 ma/sq ft. As shown in Figure 6, the hull was not uniformly protected. This was a result of poor anode distribution.

It was decided at the time of the 1953 drydocking, to change the installation to include one-hundred-twenty 60-lb anodes in six groups of 20 each port and starboard at the stern, also fore and aft the roll keel. In an effort to eliminate the excessive current in the vicinity of the anodes, several vinyl and epoxy coating systems were applied to the hull, immediately adjacent to the anode strings. Also, in order to obtain additional information on the continued absence of marine fouling, a 3-foot square area of the hull, located amidship, was sandblasted and left unpainted. The remainder of the hull was given one coat each of anti-corrosive and anti-fouling paint.

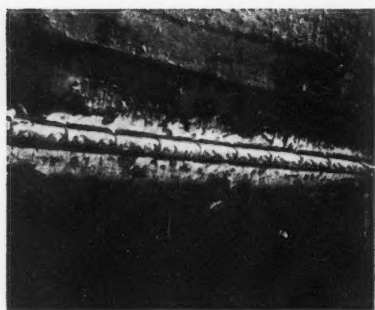


Figure 5—Evidence of excessive current density adjacent to the anodes with subsequent removal of paint coatings.

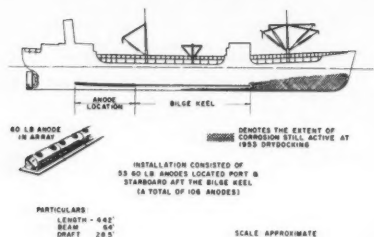


Figure 6—Method of anode installation on SS Marine Chemist during the period 1953-1954.

Observations at the drydocking in 1954 revealed that:

1. Cathode potentials, taken during the year 1953-54 correctly indicated adequate protection. Figure 7 shows that only an area within 50 feet of the bow remained partially active to corrosion. Protection was complete in the aggressive stern area.
2. The distributed anode system improved the effectiveness of the available protective current.
3. Based on the new distribution, the 60-lb anode demonstrated a life of approximately 18 months, which did not conform to an annual drydocking schedule.
4. Paint stripping in the anode vicinity was unsightly and a continued objection.
5. The vessel showed no fouling. This included the sandblasted and paint-free area amidship.
6. Although anode installation costs had been lowered and the anti-corrosive painting had been eliminated, economics could be improved.

Although some corrosion still persisted at the bow despite the improved distribution system, it was not considered serious since an industry-wide survey on ship maintenance costs indicated that repairs in this area were minor in relation to those in the stern area. Even so, an increased understanding of the current densities required at the bow was deemed an essential part of the test program. Therefore, at the 1954 drydocking, two groups of ten 60-lb anodes were added to the system and installed near the bow. Figure 8 illustrates the eight group distribution system.

Results of research that began in 1953 on an anode featuring a new shape and core arrangement, were encouraging. This anode, shown in Figure 9, could be bolted or welded to the hull and was

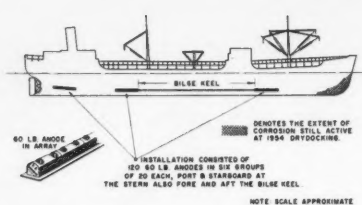


Figure 7—Method of anode installation on SS Marine Chemist during the period 1953-1954.

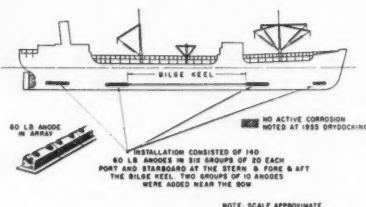


Figure 8—Method of anode installation on SS Marine Chemist during the period 1954-1955.

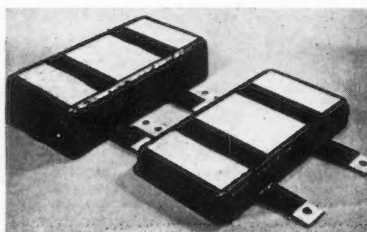


Figure 9—Plastic-coated weld or bolt-type anodes. The 44 and 24-lb anodes are shown.

completely enveloped in a tough, serviceable plastic. Current could be controlled by removing specified amounts of plastic from the anode surface. The plastic coating acted as an additional resistance in the electrolytic circuit, common to all paths. This increases the resistance of the short current paths to values more nearly approaching the larger current paths through the seawater. As the ratio of the resistances of the long and short paths approaches equality, current distribution is regulated more directly by cathode potential variations. This suggested that it was possible to eliminate excessive current in the immediate vicinity of the anode. Two basic designs were investigated: A large anode, weighing 44 lbs, for use on ocean-going vessels which would allow a one or two year life, and a 24-lb unit for use on smaller vessels.

Several of these experimental coated anodes were welded to the hull of the SS Marine Chemist at the 1954 drydocking.

At the 1955 drydocking, some important questions concerning the cathodic protection of an active vessel were answered. The following points were noted:

1. Inspection revealed that all underwater areas, including the bow, had been effectively protected.
2. Anodes installed in 1954 were only 50 percent depleted.
3. Current distribution over the hull was uniform at a density of 4.7 ma/sq ft.

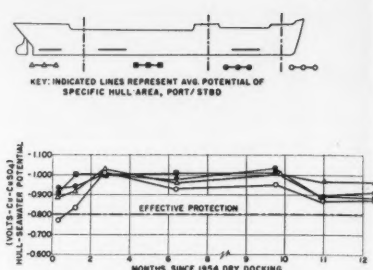


Figure 10—Hull potential time study of SS Marine Chemist for the period 1954-1955.

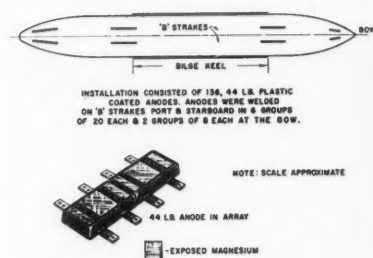


Figure 11—Installation of eight anode groups on the hull bottom of SS Marine Chemist for the period 1955-1956.

Figure 10 gives half-cell potential measurements for the 13-month interval.

4. The vessel showed absolutely no evidence of fouling.
5. Experimental coated anodes installed in 1954 performed satisfactorily.

Complete protection was brought about by the eight group anode system that furnished additional current forward. Also, it was noted that the current density required to protect an active vessel decreases with time.

Prior to the 1955 drydocking of the SS Marine Chemist, work on the previously discussed coated anode was essentially complete. The installation for the operational year 1956 consisted of one-hundred-thirty-six 44-lb coated anodes, welded along the 'B' strakes. As illustrated in Figure 11, there were three groups of 20 anodes and one group of 8 anodes, located port and starboard. Transfer of the anode strings from the roll keel area to points on the 'B' strakes substantially reduced the amount of staging required. (All anodes were installed from low shoring at dock level).

As a result of the absence of marine fouling observed since 1951, anti-fouling paint was not applied during the 1955 drydocking. Also, because of the success of cathodic protection, all anti-corrosive paint, primer coats, and cleaning were eliminated.

It was evident that the use of a coated anode, with its improved current distribution was a step toward favorable economics.

An unfortunate grounding of the SS Marine Chemist in May, 1956, severely damaged the cathodic protection system, installed in October, 1955. The subsequent dry dock inspection revealed corrosion control conditions identical to those noted at the last inspection. The vessel remained free of fouling.

Figure 12 shows field data, relating to the performance of the coated anode. These data can be used to predict the life of an anode in an array, or string.

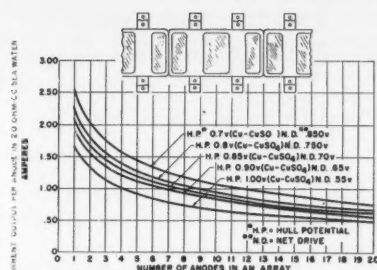


Figure 12—Performance of plastic-coated anodes in an array (44 and 24-lb units).

For the 1956 installation, 44-lb anodes were used in a series of twelve strings, 6 port and 6 starboard, with ten anodes per string. Figure 13 shows the anodes again located on the port and starboard B' strakes.

SS Marine Dow Chem

It was highly desirable to include work performed on a new vessel. This opportunity was presented in 1953 during construction of the 18,000 ton chemical tanker, *SS Marine Dow Chem*. Prior to launching in December, 1953, this vessel was fitted with one-hundred-eighty 60-lb anodes in six strings of 30 anodes each, port and starboard. The original installation pattern was similar to that on the *SS Marine Chemist* in 1953.

In October, 1955, after a service interval of 22 months which included two preliminary drydockings, the vessel was placed in dry dock for her first major inspection. It was observed that 80 percent of the wetted area was completely protected. This included an area extending from the stern to a point just forward of the leading anode strings. Substantial protection was afforded an additional 10-15 percent of the hull on the bow ahead of the forward anode strings. The remaining 5-10 percent of the bow area indicated minor corrosion attack in the form of nodules running fore and aft. Potential measurements taken during this interval (Figure 13) correlated very well with visual observations.

Reduced cathode potentials at the bow indicated that the anode group forward of the bilge keels was expended two to three months prior to drydocking. The anode strings just aft the bilge keels were uniformly reduced to a weight of 3 to 4 lbs per anode. Those just forward of the stern frame were somewhat larger, weighing approximately 8 or 9 lbs per anode. A current density range of 5.7-1.0 ma/sq ft existed on this hull during the interval cited.

During the 1955 drydocking, one-hundred-eighty 68-lb anodes were installed on studs at the original anode locations. The experimental 68-lb anodes are a modification of the previously described bolt-on anodes, having a square cross section and incorporating a plastic coating on the bottom and sides.

Before the ship re-entered service, the bow was given a standard 3-coat paint system in an effort to reduce the current demand. The remainder of the hull received no maintenance coating below the light-load line.

Economics

Tables 1 and 2 compare the maintenance costs of unprotected ships with the cost of cathodic protection. This evaluation of economics of cathodic pro-

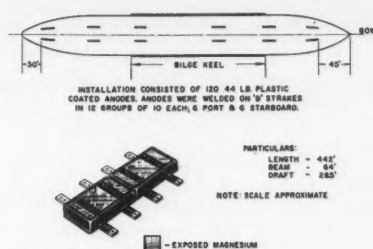


Figure 13—Method of anode installation on *SS Marine Chemist* for the period 1956-1958.

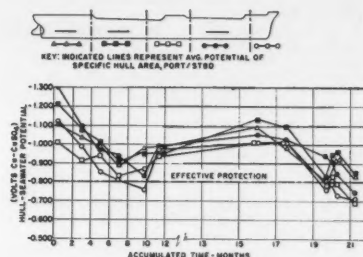


Figure 14—Hull potential time study of *SS Marine Dow Chem* (initial 22 months).

TABLE 1—Maintenance Costs If Ships Were Not Cathodically Protected

	SS Marine Chemist 12,500 Tons 1-Yr. Period	SS Marine Dow Chem, 18,000 Tons 2-Yr. Period
Hull paint (material and application).....	\$3150	\$7020
Zincs.....	350	700
Stern maintenance.....	1000	2000
Drydock time.....	(2 Days) 3500	(4 Days) 10080
Total maintenance.....	\$8000	\$19800
Per year maintenance.....	\$8000	\$ 9900

TABLE 2—Cathodic Protection Costs

	SS Marine Chemist 1-Yr. Anode Life	SS Marine Dow Chem, 2-Yr. Anode Life
Material and engineering.....	\$3760	\$6850
Installation costs.....	1630	2700
Paint.....	None	2000
Drydocking.....	(1 Day) 1700	(2 Days) 5040
Total Cathodic protection cost.....	\$7090	\$16590
Per year cathodic protection cost.....	\$7090	\$ 8295

ANNUAL SAVINGS ARISING FROM CATHODIC PROTECTION

	SS Marine Chemist	SS Marine Dow Chem
Routine maintenance cost (Table 1).....	\$8000	\$9900
Cathodic Protection costs (Table 2).....	7000	8295
Annual maintenance savings.....	\$ 910	\$1605

tection compares the costs of providing such protection to only routine preventive maintenance costs common to the marine industry. Costs of long-term plate replacement, propeller repair, or replacement, excessive drydocking time, fixed costs of operation, and loss of revenue, although extensive, are difficult to estimate and have not been considered.

The following have been readily apparent and were considered in establishing economics for this program.

1. Stern frame and rudder maintenance were eliminated.
2. Traditional stern 'zincs' were eliminated.
3. Maintenance coatings have been either completely eliminated, or their effective service life has been extended.
4. Time in dry dock has been reduced.
5. Use has been made of the correct anode weight, which gives maximum performance for the interval exposed.
6. Anode installation costs have been reduced from a high of \$46/anode to a more realistic figure of \$7-\$10/anode.

Experimental work is continuing on several aspects of this program. In this connection particular emphasis is being placed on more economical anode coatings and reduced installation procedures.

Summary for the Corrosion Investigator

After critically examining laboratory and field experiences, some valid considerations as to installation and design technique may be advanced as follows:

1. Determine the corrosion status and extent of marine fouling normally encountered prior to the initial installation.

2. Design for a minimum initial density of 5 milli-amperes per square foot of wetted surface.

3. Distribute the anode strings as uniformly as possible over the hull surface.

4. Design for a two-year life. The life of magnesium anode strings is directly proportional to string length.

5. A cathode potential of 0.800 volt Cu-CuSO₄ should be considered a minimum value for effective protection.

Summary for Ship Owners

1. Underwater hull corrosion can be effectively eliminated by cathodic protection so that primer and anti-corrosive coatings can be discontinued.

2. On the vessels considered in this study, annual maintenance costs have been reduced through the use of cathodic protection.

3. Insurance against long-term corrosion damage is a by-product gain of cathodic protection.

4. Elimination of anti-fouling paint on the vessels considered was based solely upon the absence of marine fouling during the course of the tests.

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6. K. N. Barnard and G. L. Christie. Informal Proceedings, Wrightsville Beach, Sea Horse Inst., June 7-9, 1950.
7. B. Douglas and C. F. Schrieber. Plastic

Coated Magnesium Anodes. Paper presented at a meeting of the South Central Region, NACE, Houston, Texas, October, 1955.

DISCUSSION

Question by C. J. Fritts, Houston, Texas:

You mentioned that there was no fouling on your vessels when cathodic protection was used. Had there been fouling previously?

Reply by C. F. Schrieber:

Anti-fouling had been used consistently prior to the cathodic protection

tests. Presumably there was *none* since no evidence is available that the application of cathodic protection eliminates or reduces fouling.

Question by Frank S. Bird, New Orleans, Louisiana:

When the *Marine Chemist* went aground, was any hull damage sustained as a result of the anodes tearing away hull plating?

Reply by C. F. Schrieber:

No damage resulted from the anodes.

Any discussions of this article not published above will appear in the June, 1958 issue

TECHNICAL PAPERS ON CORROSION WELCOMED

Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.

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Thermal and Osmotic Countermeasures Against Some Typical Marine Fouling Organisms*

By DENIS L. FOX and EUGENE F. CORCORAN

Introduction

INDUSTRIAL OPERATIONS involving the continuous use of sea water require that intake and discharge conduits be protected against fouling of their inner walls by perennial sedentary, hard-shelled marine animals, such as mussels, barnacles, tube-worms, etc. Various countermeasures have been tried, including heat, fresh water, stagnant water, chlorination, dewatering of tunnels and periodic mechanical scraping, with varying degrees of expense and effectiveness.

It has been determined that thermal treatment is the most feasible of the various countermeasures to be incorporated into the construction of a steam plant, and to be thereafter employed at regular intervals in its operation. Thermal control of marine fouling has been successfully practiced at the Redondo Steam Station of the Southern California Edison Company for nearly a decade, by discharge of the spent (i.e., warmed) circulating water through each of the pair of tunnels which serve alternately as intake and discharge conduits.¹

Among the numerous local marine animals, mussels of the genus *Mytilus* have been found to be the most prominent members of fouling communities. They are also the most resistant of the common animals toward countermeasures such as heat,² osmotic changes or poisons. Therefore they were used to test organisms in investigations in which it was desirable to determine the comparative tolerance of the two most common mussel species of the Pacific coast to immersion in fresh water at ambient temperatures, and in sea water at elevated temperatures. (These marine animals are the California sea-mussel, *Mytilus californianus* and the cosmopolitan bay-mussel, *M. edulis*.)

Antifouling measures should be applied while invading mussel populations are changing, or have recently changed, from their microscopic, free-swimming larval or veliger stage, to the attached bivalve phase. For this reason very small specimens of fairly uniform length were selected for the investigation.

Groups of 10 freshly collected and carefully separated, healthy young mussels were placed into each of a series of 30-ml Gooch crucibles. The mouth of each such container was then covered with a small square of plastic screen, secured by a rubber band, to ensure the containment of the mussels throughout the experiment.

Series (usually 10) of mussel populations, thus contained in groups of 10 each, were then exposed simultaneously to the controlled experimental conditions in a large pan of water. At measured time-



Fox

Corcoran

DENIS L. FOX is professor of marine biochemistry at the Scripps Institution of Oceanography, University of California, La Jolla, where he has served on the faculty for 26 years. He received a bachelors degree in chemistry from the University of California at Berkeley in 1925. After four years in industrial chemistry, he returned to graduate work at Stanford, where he received his doctorate in biological sciences (biochemistry) in 1931. Dr. Fox was a Rockefeller Research Fellow at Cambridge University in 1938-39, and a Guggenheim Foundation Fellow in 1945-46. He is the author of numerous papers dealing with marine animal life.

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intervals, a crucible of mussels was removed from the common experimental environment and drained of its water. Then it was transferred immediately to fresh, daily renewed, continuously aerated sea water, and inspected at frequent intervals.

Mussels exhibit injury by (1) failure to spin new, attaching byssus threads (re-attachment may sometimes be delayed, but this is diagnostic of lethality if the delay is excessive); (2) gaping apart of the paired shell-valves, especially if this persists despite mechanical shock (e.g., tapping the shell gently with a glass rod); (3) persistent "sulking" or failure to part the shell-valves for long periods (often observed in very young animals, which, unlike older ones, may, in some cases, die without their shell-valves being pulled open by the action of the tough opening hinge). Persistent gapers were safely regarded as dead or dying, and

Abstract

Tests were conducted to determine the tolerance of mussels of the genus *Mytilus* to immersion in fresh water at ambient temperatures and in sea water at elevated temperatures. It was found that young bay mussels, which constitute the most serious sedentary fouling organisms in local sea conduits, may be killed in about 50 minutes at 106° F. in an hour at 100° F. in 7 hours at 95° F. and within 14 hours at 90° F. They may survive for as long as four days at 82° F. and indefinitely at 77° F. Tests results indicate that it is impractical in most cases to apply fresh water as a lethal agent for the mussels in sea water conduits. A countermeasure found to be effective was the discharge of warm sea water through conduits.

3.3.2

were removed, while those failing to attach byssus threads, whether sulkers or intermittently open, were given a maximum period of three days of continued observations. Sulkers or unattached individuals seldom if ever survive after exhibiting such signs of failure for a day or more.

The population of survivors (i.e., mussels that were re-attached, sensitive, and filtering water after three days) was recorded from each lot of 10, and was plotted as indicated in the accompanying charts. It will be observed that the ubiquitous bay-mussel (*Mytilus edulis*) is somewhat more tolerant toward fresh water and toward raised temperatures than is the sea mussel (*M. californianus*).

Experiments with Fresh Water

One hundred young mussels, 7.5 to 10 mm long, were divided into groups of 10 each, in 10 Gooch crucibles. All of the crucibles were then placed in a large enamel pot completely filled with fresh water (about six liters). This pot was closed off at the top with an inverted lid, in order to exclude air space.

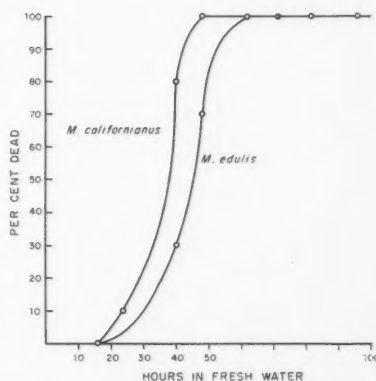


Figure 1—Death rate of *M. californianus* and *M. edulis* in fresh water.

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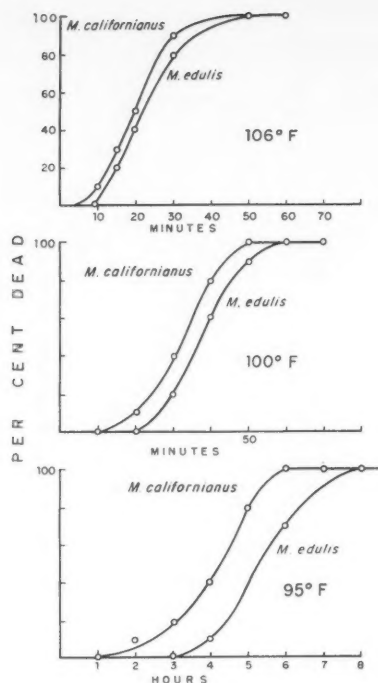


Figure 2—Death rate of *Mytilus californianus* and *M. edulis* (1 to 3 mm in length) at 95 F, 100 F and 106 F in sea water.

At intervals of 16, 24, 40, 48, 63, 72, 88, 96, 112 and 136 hours, a crucible was removed from the fresh water, drained, labeled and immersed in a reservoir of fresh aerated sea water. Figure 1 indicates that about 48 hours of immersion in fresh water represent a lethal period (i.e., 100 percent dead) for young sea mussels, and some 63 hours for the bay mussel. All exposures were made at ambient temperatures close to 72 F.

This comparatively greater tolerance for fresh water on the part of *Mytilus edulis* is consistent with its ability to colonize brackish waters and river mouths, wherein the other species fails. The 63-hour period required for killing the population also

TABLE 1—Thermal Death Times of Mussels at Various Temperatures

TEMPERATURE		THERMAL DEATH TIME FOR 100%	
Degrees F	Degrees C	<i>M. californianus</i>	<i>M. edulis</i>
106	40.9	40 minutes	50 minutes
100	37.8	50 minutes	60 minutes
95	35.0	6 hours	7 hours
90	32.2	12 hours	14 hours
85	29.4		41 hours
82	27.8		96 hours
77	25.0		∞ (indefinite survival)

suggests some infeasibility of employing fresh water as an antifoulant for industrial sea water conduits.

Temperature-Time Threshold Experiments

In this series also, freshly collected juvenile mussels (1-3 mm long), differentiable as to species under low power of a stereoscopic microscope, were segregated in the customary series of screened and bottom-perforated crucibles in the usual way. They were then exposed to controlled temperature conditions for measured time-intervals, removed, drained of superfluous water, transferred to fresh, aerated sea water and inspected (see Figure 2). The thermal death times at given temperatures are given in Table 1.

It is evident from the table and the charts that young bay mussels, which constitute the most serious sedentary fouling organisms in local sea water conduits, may be killed in about 50 minutes at 106 F, in an hour at 100 F, in 7 hours at 95 F, and within 14 hours at 90 F. They may survive for as long as four days at 82 F, and indefinitely at 77 F.

In the course of these investigations, an interesting discovery was made relating to the extraordinary heat-resistant species, the so-called ribbed mussel, or Adams' mussel *Mytilus (Hormomya) adamsianus*. This species occurs along the west coast from Santa Barbara to Panama, and on the Galapagos Islands, and is easily confused with another ribbed-shell species, *Septifer bifurcatus*.

Specimens of this ribbed mussel, re-

turned to fresh, aerated sea water after 3 hours exposure to sea water at a temperature of 106 F, remained closed for at least 48 hours, after which interval they once again moved about and spun their byssus threads for attachment. Another lot of the same species, exposed to the same warmed water for 3½ hours, resumed their activities only after some 60-72 subsequent hours in cool, aerated sea water. A thermal death interval of 2½ hours was finally established at a temperature of 113 F.

These small mussels are relatively sparse, however, apparently being crowded out by their large *Mytilus* relatives. They achieve a length of only an inch or less, and are hardly to be regarded as a threat to marine installations.

From the investigations reported here, it would hardly appear practical to apply fresh water as a lethal agent, even for very young *Mytilus* of either species, unless it were economically feasible to maintain the exposure for a 3-day period. When, on the other hand, it is feasible to warm the sea water (e.g., by recirculation, if necessary, of that which may have already acquired some heat from the condenser tubes) and to discharge this warmed water through the conduits, this is an effective antifouling measure.

In Southern California installations, for example, sea water warmed to 100-106 F and discharged through an alternative intake tunnel for an hour, or at 95 F for 7 hours, applied say at tri-weekly intervals during the season of potential fouling by mussels* should continue to prevent the attachment of these mollusks and allied forms.

In general, thresholds of thermal tolerance may be expected to show wide variability, depending upon latitude. Marine animals inhabiting equatorial waters will exhibit a tolerance for higher temperatures than proved lethal in the present studies, and inhabitants of northerly waters will succumb at considerably lower temperatures.

Reference

1. W. L. Chadwick, F. S. Clark, and D. L. Fox. Thermal Control of Marine Fouling at Redondo Steam Station of the Southern California Edison Company. *Trans. ASME*, (1950) Feb.

* This period will be from about mid-March to mid-October, depending upon ambient water temperatures of 60 F and above.

Any discussions of this article not published above will appear in the June, 1958 issue

NACE TECHNICAL COMMITTEE REPORT

Reinforced (Faced-Brick/Resinous Cements) Linings

A Report of NACE Unit Committee T-6A on Organic Coatings
And Linings for Resistance to Chemical Corrosion,⁽¹⁾ Prepared
By Task Group T-6A-14 on Organic-Brick Covered Coatings⁽²⁾

Foreword

COMMITTEE T-6A is organized for the purpose of assembling and disseminating to the corrosion engineer, factual and quantitative data on the performance and limitations of the various organic materials that are successfully used in coatings and linings. While every attempt is made to be factual in the coverage of application and chemical resistance tables and physical properties, it nevertheless should be recognized that changes in compounding formulations of organic materials for coatings or linings enhance or detract from their inherent corrosion resistance characteristics. Under the circumstances, these reports and recommendation lists must be viewed as showing average properties only. The possibility of changes in chemical and physical characteristics as produced by various manufacturers or applicators of the material should be kept in mind.

Definitions

The term "Reinforced Tank Linings" is intended to refer to resins or plastics, with or without a filler, used in conjunction with brick or tile or with a fabric reinforcing. These materials generally consist of a solvent-free liquid resin with an inert powder filler mixed to a stiff mortar consistency and hardened at ordinary temperature by a setting agent added with the powder filler. These special cement mortars usually are applied by means of a plasterer's or bricklayer's trowel or by means of high pressure spray systems. The information included in this report is necessarily general in nature, since there are differences within types of materials and according to different brands. In doubtful areas and for specific information, it is advisable that the suppliers' recommendations be obtained.

Furan Resin Cements

Liquid furan resin binder may be formed by the polymerization of fur-

Abstract

Almost any synthetic resin in liquid form or which can be dissolved in a common solvent is a basis for a corrosion resistant cement mortar. Broad application of the resins in brick and tile linings depends upon such factors as attainable physical properties, chemical resistance, and adaptability for easy handling.

Physical properties and corrosion resistance to various chemicals are listed for furan, phenolic, polyester and epoxy resin cements. Corrosives in which these resins were tested include 13 acids, 5 alkalis, 4 gases, 3 oils, 7 oxidizing agents, 13 salts and 9 solvents. Physical and mechanical properties listed include weight, porosity, tensile strength, compressive strength, flexural strength, modulus of rupture and coefficient of thermal expansion. The use and preparation of these cements also is discussed.

Miscellaneous corrosion resistant cements discussed briefly include those made from asphaltic and bituminous materials, sulfur cements, and silicate cements. 5.4.3

furyl alcohol, by the co-polymerization of furfural and furfuryl alcohol, or by the condensation of furfuryl alcohol and formaldehyde. These resins are usually supplied for use as viscous liquids, varying in viscosity from 100 to 500 cps.

Another type of furan liquid resin binder is prepared from furfural and acetone. These liquid resins have a relatively low viscosity but are handled in the same way as the more viscous binders.

At the time of use, the liquid furan resin is mixed with an inert powder such as carbon, coke flour, silica flour, asbestos, or barytes, containing an acid catalyst. This is done to promote further polymerization to a hard infusible state.

Successful and extensive use of the furan resin cement mortars in brick and tile linings for protective linings has been made in practically all kinds of tanks and process vessels. These cements also have been used with glass fabric and other reinforcing agents to form tank linings, and have been cast and molded to form small tanks, pipe, fume ducts, and other chemical processing equipment.

The furan resin cements have a wide range of chemical resistance and are



⁽¹⁾ C. G. Munger, Amercoat Corp., South Gate, California, chairman.

⁽²⁾ R. W. Hall, Stebbins Engineering and Manufacturing Co., Watertown, N. Y., chairman.

TABLE 1—Typical Physical and Mechanical Properties of Resins

	Furan	Phenolic	Polyester	Epoxy
Weight (In Pounds) Per Cubic Foot.....	100	112	120	95
Porosity, Percent.....	<1	2	1	<1
Tensile Strength, psi.....	1,200	1,200	1,200	1,200+
Compressive Strength, psi.....	12,000	10,000	12,000	15,000—20,000
Flexural Strength, psi.....	5,000	5,000	5,000	6,000
Modulus of Rupture, psi.....	1,200	1,400	1,500	1,500
Coefficient of Thermal Expansion, °F.....	11.5x10 ⁻⁶	8x10 ⁻⁶	.....	10x10 ⁻⁶

TABLE 2—Corrosion Resistance of Cements

Corrosion Media	RESISTANCE OF RESINS*			
	Furan	Phenolic	Polyester	Epoxy
Acids:				
Acetic, dilute.....	R	R	LR	R
Acetic, glacial.....	R	LR	NR	NR
Chromic.....	NR	LR	LR	NR
Citric.....	R	R	.....	R
Fatty Acids.....	R	R	R	R
Hydrochloric.....	R	R	R	R
Hydrofluoric.....	R (with carbon filler)	R (with carbon filler)	LR	R (carbon filled)
Hypochlorous.....	LR	.....	R	NR
Nitric.....	NR	.....	.....	NR
Nitric, 2 Percent.....	.....	.....	LR	.....
Nitric, over 2 percent.....	.....	.....	NR	.....
Nitric, over 5 percent.....	.....	NR	.....	.....
Nitric, under 5 percent.....	.....	LR	.....	.....
Phosphoric.....	R	R	R	R
Sulfuric, 50 percent.....	R	R	R	R
Sulfuric, 80 percent.....	LR	LR	NR	NR
Sulfuric, concentrated.....	NR	NR	NR	NR
Alkalies:				
Ammonium Hydroxide.....	R	NR	NR	R
Calcium Hydroxide.....	R	LR	NR	R
Sodium Hydroxide, 1 percent.....	R	NR	NR	R (carbon filled preferred)
Sodium Hydroxide, 10 percent.....	LR**	NR	NR	R "
Sodium Hydroxide, 25 percent.....	LR**	NR	NR	R "
Gases:				
Chlorine.....	NR	LR	LR	NR
Bromine.....	NR	NR	LR	NR
Sulfur Dioxide.....	R	R	R	R
Hydrogen Sulfide.....	R	R	R	R
Oils:				
Animal.....	R	R	R	R
Vegetable.....	R	R	R	R
Mineral.....	R	R	R	R
Oxidizing Agents:				
Hydrogen Peroxide.....	.....	.....	R	LR
Hydrogen Peroxide, 3 percent.....	LR	.....	.....	NR
Bleach.....	.....	LR	R	.....
Acid Bleach.....	.....	NR	LR	.....
Alkaline Bleach.....	.....	NR	R***	R***
Perchloric Acid, 10 percent.....	R***	R***	R***	R***
Concentrated Oxidizing Agents, all types.....	NR	NR	NR	NR
Chlorine Solutions.....	LR	LR	R	NR
Chlorine Dioxide Solutions.....	NR	NR	R	NR
Salts:				
Alum.....	R	R	R	R
Copper Sulfate.....	R	R	R	R
Ferric Salts.....	R	R	R	R
Magnesium Sulfate.....	R	R	R	R
Potassium Permanganate.....	R	R	R	R
Silver Nitrate.....	R	R	R	R
Sodium Bisulfite.....	R	R	R	R
Sodium Carbonate.....	R	LR	R	R
Sodium Chloride.....	R	R	R	R
Sodium Hypochlorite.....	LR	NR	LR	NR
Sodium Nitrate.....	R	R	R	R
Sodium Sulfate.....	R	R	R	R
Sodium Sulfite.....	R	R	R	R
Solvents:				
Alcohols.....	R	R	R	R
Glycols and Glycerine.....	R	R	R	R
Acetone.....	R	R	NR	LR
Aniline.....	NR	LR	NR	NR
Methylene Chloride.....	NR	NR	NR	LR
Carbon Tetrachloride.....	R	R	LR	R
Chloroform.....	R	R	LR	LR
Ethyl Acetate.....	R	R	NR	R
Gasoline.....	R	R	R	R

* R—Generally recommended; LR—Limited recommendation (test before using); NR—Not generally recommended.

** For caustic alkali service, carbon filled mortars should be used. In the lower range of temperatures, chemical resistance is usually quite satisfactory but at high temperatures mortars of different brands vary in caustic alkali resistance and simulated field test should be made.

*** Handling of perchloric acid in organic materials is hazardous. Dangers of explosion will ordinarily be basis for rejection of resin mortars.

suitable for service in non-oxidizing acids, alkalies, salts, gases, oils, greases, detergents, and most solvents at temperatures up to 375 F. Chemical resistance and heat resistance under varying conditions depend somewhat upon the type

of filler; slight differences may result from variations in the basic resins and from the hardening systems.

Typical physical and mechanical properties of these and other cements are given in Table 1. Their corrosion resist-

ances to various chemicals are included in Table 2.

Phenolic Resin Cements

The first synthetic resin cements to be used in large scale corrosion resistant brick linings were based on the liquid phenol formaldehyde resins. They have been used extensively for about 25 years but for the most part have been replaced in recent years by the newer and more generally resistant furan resin cements.

The phenolic resin cement mortar is prepared by mixing an A stage liquid resin with an inert powder filler containing an acidic catalyst. The powder filler may consist of carbon, coke flour, silica flour or other inert material. The acidic catalyst promotes the final polymerization of the resin to a hard infusible state. These cements have been used in practically the same way as furan resin cements but have been somewhat more restricted by their relatively poor resistance to strong alkalies and by their lower resistance to many solvents.

The stability or shelf life of the liquid resin is not as good as that of the liquid furan resins. It is generally necessary that the phenolic liquid resin for the cement be stored at 60 F or lower. In some cases, even at 60 F a shelf life of no greater than six months can be expected. On the other hand, the phenolic resin cements have performed at least as well as the furan resin cements in many conditions and may be found to be superior under exposure to some mild oxidizing conditions. The phenolic resins cements are suitable for service in a wide variety of acid solutions, very mild alkaline solutions, gases, and many solvents up to 350 F.

Polyester Resin Cements

The polyester resin cement mortars have been in use for about four years and have found ready applicability in brick and tile linings for various bleaching vessels. These cements are based on unsaturated polyester resins formed by the condensation of unsaturated dibasic acids such as maleic and phthalic acids with styrene monomer. A wide variety of suitable liquid polyester resins is available for compounding with inert fillers and hardening agents.

All of the proprietary cement mortars now available are supplied with a silica filler. There is no reason why other inert fillers cannot be used, but because of the specific uses of these cement mortars and because of the limitations of the resin, no advantage ordinarily can be gained by the use of a different type of filler. Proprietary cements are supplied as a two part system, (i.e., a viscous liquid polyester resin containing a small quantity of a promoter or activator, and a silica flour filler containing a small quantity of a peroxide catalyst.)

Although the physical and mechanical properties and also the chemical resistance of this type of cement mortar can be varied greatly because of the wide choice of available resins, there are more definite limitations which restrict the mortar to specific uses. Therefore, these mortars cannot be recommended for resistance to such a wide range of conditions as either the furan resin cements or the phenolic resin cements.

The polyester resin cements are limited by lack of resistance to strong alkalies and to many solvents. The heat resistance is relatively low and they rarely can be considered for use at tem-

peratures above 250 F. Their potential and advantageous use depends upon their resistance to mild oxidizing agents such as bleach solutions, and upon the possibility of superior adhesion or bonding to Portland cement or alkaline surfaces, to metallic surfaces and to dense or glazed surfaces.

Polyester resin cements have not been used very extensively up to the present time and it is likely that their future use will be more for specific conditions than for general use. This type of material received its impetus for use as a result of the need for such a material in chlorine dioxide bleaching.

Epoxy Resin Cements

Within the last two or three years the newer "epoxy" resins have been compounded with fillers for use as cement mortars. Proprietary cements based on these resins have been made available but extension of their use has been limited by their relatively high cost. They have found application where specific properties have been required and which could not be satisfied by other cement mortars.

The epoxy resins are prepared by the alkaline condensation of bisphenol and epichlorhydrin. Various grades of these resins are available for use in cement mortars and properties of the mortars can be varied accordingly. In general, however, the most advantageous properties from a service standpoint can be obtained from the more viscous resins which are the more difficult to handle.

All types of inert fillers may be compounded with these resins and hardened at room temperature by means of amines as catalysts. By use of properly chosen and designed fillers and by use of well chosen catalyst and curing systems, the heat resistance and chemical resistance to hot alkaline solutions can be brought to exceed those resistances of other resin cements. However, the usual proprietary cement of the epoxy type has been compounded for general use and for convenience in handling and this has resulted in some compromise of the service properties. In general, the epoxy resin cements have excellent resistance to non-oxidizing acids and to alkalis. The resistance to solvents and to heat is not outstanding, but special formulations which would greatly improve these properties can be prepared at the sacrifice of ease of handling. For

the proprietary cements the heat resistance is considered to be no greater than to withstand a temperature of 250 F.

Unusual advantages of the epoxy resin cements in comparison with other resin cements result from their excellent adhesion to Portland cement surfaces, metals and to other polished or glazed surfaces. Excellent physical and mechanical properties are possible if the materials are capably handled and particularly if special formulations are used.

Other Corrosion Resistant Cements

Almost any synthetic resin in liquid form or which can be dissolved in a common solvent is a basis for a corrosion resistant cement mortar. Broad application depends upon several factors such as attainable physical properties, chemical resistance, and adaptability for easy handling so that the number of materials for general use is small. Specialty materials can be and have been produced to conform with special requirements involving such considerations as appearance and color, food laws, adhesion to particular surfaces or materials, extreme flexibility or extreme rigidity, and insulation plus chemical resistance. All of the applications and possible applications of synthetic resins in this respect cannot be reviewed in this report beyond mention of the fact that a wide variety of resins have been used in reinforced linings of various types and they include the vinyls, coumarone-indene resins, urea-formaldehydes, melamines, acrylates, polyamides, rubbers and others.

There are other important corrosion resistant cements not based upon synthetic resins but which should be mentioned in this report in order to present a complete survey. These are produced from natural products or from inorganic materials.

Asphaltic and bituminous materials have been used extensively for low temperature applications. They are supplied with and without fillers ordinarily for service within a limited temperature range. Such cements have been used to a limited extent as caulking between brick and tile but usually are used behind brickwork with or without a fabric type reinforcing as an impervious layer.

The asphaltic and bituminous materials are resistant to a wide range of acid and alkaline conditions. They are

low in cost and generally easy to handle but are severely limited by low resistance to solvents and to heat. They may be applied either as mastics which depend upon evaporation or solvent, or as hot melt compounds, or as sheets which may or may not contain a plasticizer or rubberizing compound.

Sulfur cements consist of elemental sulfur with inert fillers and organic plasticizers. They are applied as hot melt materials; linings involving their use are designed for the melting, pouring and solidifying process. Linings for vessels which are to be used for pickling of stainless steel and requiring resistance to nitric and hydrofluoric acids have been standardized to consist of carbon brick with sulfur cement (carbon filled) jointing and backing. Such linings have not been replaced by other types. The sulfur cements have been used extensively in pickling tanks of all kinds for wire, rod, bar stock and mild steel strip and sheet. The sulfur cements are classified as having good resistance to both oxidizing and non-oxidizing acids. They do not offer good resistance to heat, strong alkalis and organic solvents.

Silicate cements have been used in corrosion resistant brickwork and lining work for over half a century. Originally they consisted of a solution of silicate of soda which was mixed with a siliceous filler and allowed to set or harden by the evaporation of water. This type of cement mortar has been replaced, for the most part, by a chemical setting type of material wherein a mildly acidic agent is included with the powder filler to promote the formation of the silica gel binder from the solution. More recently, proprietary cements based on potassium silicate solutions have been made available.

The silicate cements have excellent chemical resistance to acids except hydrofluoric and related acids. They have good heat resistance and may be used up to a vitrification temperature of 1500 F or higher. The disadvantageous properties are high porosity and permeability, lack of alkali resistance, and poor resistance to steam, neutral and weakly acidic solutions. It has been claimed that cements based on potassium silicate solutions have improved adhesion properties and improved resistance to strong sulfuric acid solutions.

The Copper Sulfate Electrode*

By GORDON N. SCOTT

Introduction

THIS PAPER concerns the copper sulfate electrode. By this loosely used term is meant the "copper: copper ion half cell" in which the copper ion concentration is that of a solution of copper sulfate in equilibrium with the solid salt. The object is to examine the properties of the electrode in relation to its use and to study its behavior in the field. It is not the intention to review the literature nor to duplicate the excellent laboratory study of this electrode by Dr. Scott Ewing.¹

In a recent paper on reference half cells, R. E. Hall² discussed the copper sulfate electrode and calculated its potential. In the author's paper more extended use of theory is made, with the result that there is some duplication of material already given in Hall's paper. However there are points of disagreement as well as agreement with both Ewing and Hall and others and these points are discussed.

Questions may arise in discussions of electrode potentials as to which polarity convention is used. In this paper the practice of Lewis and Randall³, and of Latimer⁴ is followed. Values in this paper for the copper sulfate and other electrodes will be, therefore, with respect to polarity in agreement with Hall and in disagreement with Uhlig⁵.

The behavior of only one commercially available copper sulfate electrode, shown in Figure 1, has been studied in use in the field. This should not be taken to mean, however, that other electrode types are unsatisfactory.

Pipe Potentials and Electrode Properties

There are three potentials of particular interest in the study of cathodic protection of pipe lines. The first of these is the "base" potential, V_b —referred to as the "static" or normal potential by some corrosion engineers. These are the potentials existing on the pipe line before any test current or cathodic protection is applied.

Potentials measured while the structure is under cathodic protection are "cathodic protection" potentials, V_c , while those measured after interruption of the cathodic protection current are "polarization" potentials, V_p . The difference between the cathodic protection potential, V_c , and the polarization potential, V_p , is the driving voltage, $\Delta V_c = V_c - V_p$; the difference between the polarization potential, V_p , and the base potential, V_b , is the polarization increment, $\Delta V_p = V_p - V_b$. The driving voltage measures the electrical effect of the applied current while the polarization increment accounts for the chemical changes caused by the transfer of current between pipe and soil. The first of



About
the
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these increments is linearly related to the cathodic protection current. The second is not so simply connected. The polarization potential, as will be shown, has a ceiling which ordinarily is not exceeded.

The incremental potentials are independent of the reference electrode potential which need remain constant only during test. In measuring the driving voltage the potentials usually are taken within a few seconds of each other, so that this determination involves only avoiding errors due to rapid changes in the polarization potential. However, to determine the polarization increment it is necessary to measure the base potentials well in advance of the tests when current is applied. In point of time this may be a few hours but more likely will be days. Accordingly, if measurements are made at times when ambient temperatures differ greatly there may be large errors in the calculated polarization increment.

In Wyoming, an electrode temperature once rose from 40 F to 80 F within an hour. This temperature change amounts to a difference in potential of 20 millivolts. Similar temperature variations have been reported to the author. One investigator stated his electrodes had reached temperatures in excess of 120 F (the limit of the thermometer used). Others have had electrodes in use freeze solidly. If it is essential, therefore, to know the polarization increment exactly, all measurements should be reduced to the standard temperature of 25 C (77 F). The author's practice in cathodic protection measurements is to note the electrode temperature as well as the time of measurement. Both of these observations can be recorded with the measured potentials with little effort.

It is important to know whether or

Abstract

Some practical aspects of the saturated copper sulfate electrode are discussed. For illustration and for comparison with an experimentally determined and commonly accepted value, the electrode potential is calculated from thermodynamic data. Simple field tests to evaluate effects of temperature, polarization, contamination, acidification, dry-earth contacts and the like are described. The necessity for information on these effects is pointed out. Some tests of direct burial electrodes are given. 4.5.3

not the base potentials are constant from day to day. Ewing says the electrode readily polarizes. Uhlig states that it exhibits effects of hysteresis and should only be used at constant temperature. If the pipe potential remains constant during the time between tests, it is desirable to know if the electrode potential remains constant at a given temperature after undergoing wide and possibly cyclic temperature changes. A change in ground surface condition as by baking in a hot sun or becoming wet by rain may be a source of substantial error. It is said the electrode potential changes with the intensity of light.

Theory

The reasons why the potentials defined above are of particular interest are many. For one example, the base potentials reflect the corrosion and other chemical processes taking place on metal below ground. These processes can be explained with the aid of the potentials,

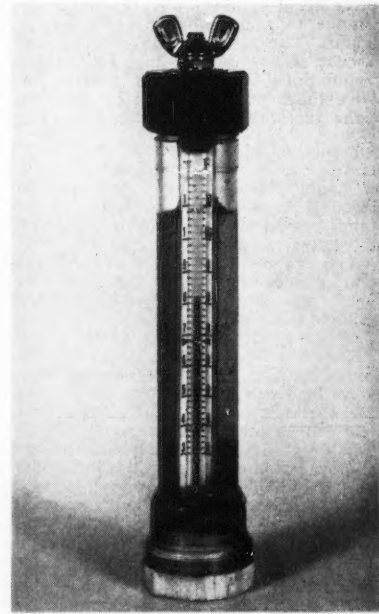


Figure 1—Copper sulfate electrode equipped with a darkroom thermometer.

* Submitted for publication November 13, 1956. A paper presented at a meeting of the South Central Region, National Association of Corrosion Engineers, San Antonio, Texas, October 23-26, 1956.

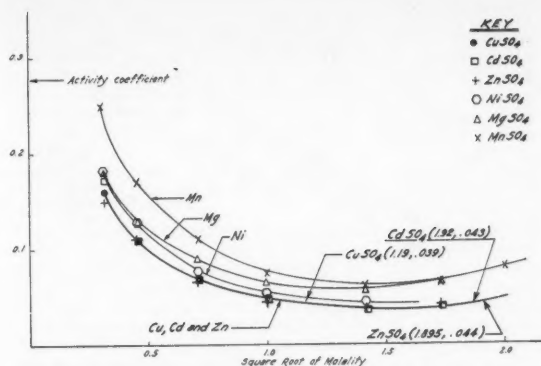


Figure 2—Activity coefficients of some bivalent metal surfaces.

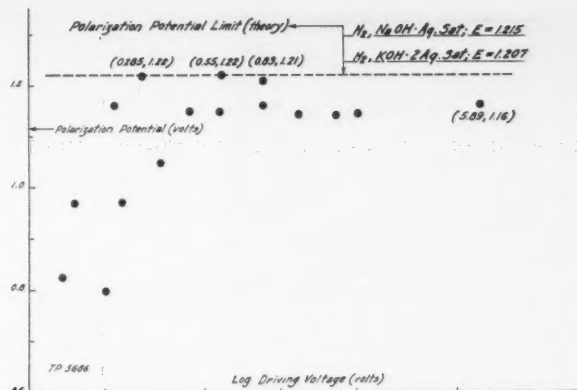


Figure 3—The polarization potential ceiling for pipe lines under cathodic protection.

once the copper sulfate electrode potential is related to the normal hydrogen electrode which is the arbitrary reference for the vast electromotive force data in the scientific literature. Then, also it can be proven that a cathodically protected pipe line behaves, at least at high current densities, like a hydrogen electrode. If this is so it is not difficult to establish a maximum safe point-of-drainage potential to avoid damage to the coating as well as to seek rational "protection criteria." It is essential, therefore, to establish this relationship between the reference electrodes.

The potential of a half cell such as the copper sulfate electrode is said to arise at the interface between the metal and the solution containing the metal ions. The absolute value of this potential cannot be stated, although the difference between it and an arbitrarily elected standard is readily computed from thermodynamic data. The customary reference for chemists and physicists is a particular value of the familiar hydrogen electrode in which hydrogen gas is maintained in equilibrium with hydrogen ion H^+ in aqueous solution. The particular value is that of a hydrogen half cell at 25 C in which the gas is at a pressure of one atmosphere (unit fugacity) and the hydrogen ion concentration is such that the activity is unity. It is assumed that this particular hydrogen electrode has zero potential. In the copper: copper ion electrode the standard electrode potential (E°) is taken as the potential when the activity of the copper ion is unity, and the reference is the standard hydrogen electrode ($E^\circ=0$).

The term "activity" was used above instead of "concentration" because it has been found experimentally that the concentration of the ions in equilibrium with the solid metal will not account for the thermodynamic properties of solutions. A correction factor called the activity coefficient is employed to correct the concentration, or more specifically the molality, expressed as moles per thousand grams of water, to "activities."

To review the above more formally Latimer is followed with the equation being written as follows:

$$E = E^\circ - (0.05916/n) \log Q \quad (1)$$

E° is the standard electrode potential and Q is the ratio of the activities of the products of a chemical reaction to those of the reactants all raised to ap-

propriate powers. In the copper: copper ion half cell, Q would be simply the activity of the copper ion. Now the activity, a , of the copper ion can be determined from the concentration or molality, m , in moles per 1000 gms of water, from the relation

$$a = \gamma m \quad (2)$$

if the activity coefficient, γ , is known.

In Equation (1), n is the number of chemical equivalents entering into the reaction. The equations for the hydrogen: hydrogen ion and copper: copper ion half cells are, therefore,

$$E = -0.05916 \log (H^+)/(H_2)^{1/2} \quad (3)$$

$$E = E^\circ - 0.02958 \log (Cu^{++}) \quad (4)$$

The symbols for the ions in parentheses in Equations (3) and (4) represent the activities of the ions in accordance with the definition of Equation (2).

In Figure 2 the activity coefficients (taken from Latimer) of copper, cadmium, zinc, nickel, magnesium, and manganese sulfates have been plotted against the square root of the molality. The activity coefficients of copper, cadmium and zinc for the concentrations shown are very nearly the same whereas those of nickel, magnesium and manganese differ. It is permissible therefore to extend the curve for the copper sulfate solution beyond the values given by Latimer to the saturation point. The solubility of copper sulfate at various temperatures is given in the International Critical Tables, Vol. 4, Page 222, and in the 24th Edition of the Handbook of Chemistry and Physics, 1940, Page 1357. According to these data the molality of copper sulfate in equilibrium with the solid phase at 25 C is 1.41 and it is from the square root that the activity coefficient is read from the curve to be 0.0390.

If then these values are substituted in Equations (2) and (4),

$$E = E^\circ + 0.0372 = -0.300 \text{ volts} \quad (5)$$

When the original numerical reduction was made by the author in 1946, the standard electrode potential E° of the copper: copper ion half cell was taken at -0.345 volts in conformity with the careful analysis of Lewis and Randall and as given in Latimer (First Edition). This was done despite the warning of MacInnes⁶ that the value could be some

6 millivolts higher at -0.339 . Accordingly, the value of -0.308 volts was used until publication of the second edition of Latimer's book in which the standard electrode potential E° was re-evaluated at -0.337 volts. This value is 8 millivolts higher than Lewis and Randall's value and in Equation (5) gives the potential of the copper: saturated copper sulfate electrode at -0.300 millivolts with respect to the normal hydrogen electrode.

This brief review of the standard electrode potential of the $Cu:Cu^{++}$ electrode has been given since there is confusion and inconsistency in the literature. The 37th edition (1954-55) of the Handbook of Chemistry and Physics still gives the obsolete value of -0.345 for the standard potential of the $Cu:Cu^{++}$ electrode. The value of -0.300 volts calculated above is 16 millivolts higher (numerically smaller) than that given by Uhlig on Page 1137. In agreement with Hall the author uses the value of -0.300 , although Hall's few measurements agree better with the standard electrode potential of MacInnes.

From this discussion it is clear that to calculate the potentials of half cells of the type $M:M^{++}$ (MSO_4 , sat.) from the equation

$$E = E^\circ - 0.02958 \log M^{++} \quad (6)$$

it is necessary to know the standard electrode potential, which can be found in Latimer, the molality of the metal sulfate at saturation and the activity coefficient which can be estimated from Figure (2). These values are reported in Table 1 for copper, cadmium and zinc. In addition to this information some knowledge of the chemistry of the metal and its sulfate is necessary if predictions about the electrode are to be made. For example, it is known that magnesium could not be used as a reference electrode because the magnesium would corrode rapidly and upset the equilibrium between the metal and its salt.

The same effect probably would occur with zinc but in addition the hydrated zinc sulfate ($ZnSO_4 \cdot 7H_2O$) occurs in two crystalline modifications—rhombic and monoclinic—and furthermore the degree of hydration changes with temperature differently for each crystalline form. The hydrated copper salt ($CuSO_4 \cdot 5H_2O$) undergoes a change at 50 C from an alpha to a beta modification with, apparently,

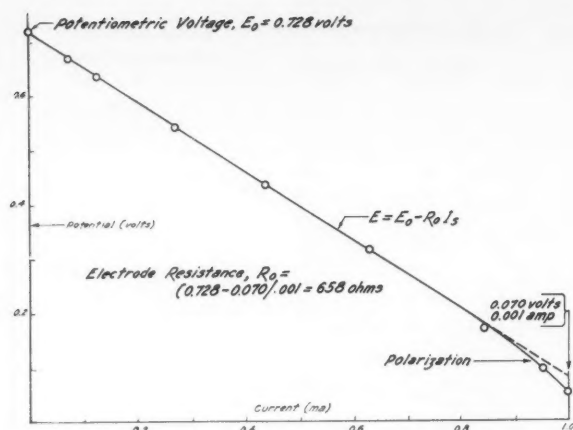


Figure 4—Polarization of the Miller copper sulfate electrode.

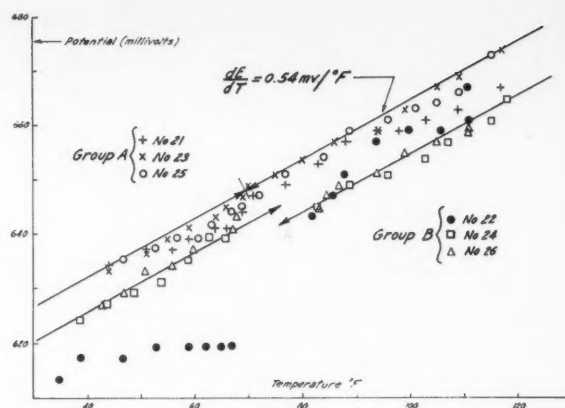


Figure 5—Temperature coefficient and hysteresis of the copper sulfate electrode.

an attendant change in potential. Cadmium sulfate, on the other hand, exhibits a single hydrated form from -15°C to 70°C and is inviting from this property as well as its potential level as a reference electrode for corrosion engineers.

To further illustrate use of formulae of the type of Equation (1), a computation will be made of the polarization potential ceiling which was stated earlier in the paper to exist. It is assumed that a pipe line under cathodic protection behaves like a hydrogen electrode. The evolved hydrogen gas is expected to be at atmospheric pressure and therefore at unit fugacity (activity). Since pH is defined as $-\log_{10} \text{H}^+$, Equation (3), which was derived from Equation (1), reduces to the simple form

$$E = 0.300 + 0.05916 \text{ pH} \quad (7)$$

with respect to the copper sulfate electrode. In this reduction a pH derived from hydrogen ion activity is assumed. If on the pipe surface the evolution of hydrogen gas from electrolysis of water has so increased the alkalinity that precipitation of either sodium or potassium hydroxide is incipient, then it can be assumed that the concentrations of the hydroxides are those of saturated solutions of these bases and the hydrogen ion activity (the pH) for either can be calculated from the dissociation constant of water

$$(\text{H}^+)(\text{OH}^-) = 1.008 \times 10^{-14} \quad (8)$$

and the solubilities of the bases at 25°C . The activity coefficient is unity since the hydrogen ion is so fantastically dilute. The solubilities of sodium and potassium hydroxides at 25°C are given in the International Critical Tables (Vol. 4, Pages 235, 239). The hydrogen ion concentration (activity) is calculated from Equation (8) and substituted in Equation (7). The several values are respectively: Molality = 28.3, 21.2; pH = 15.45, 15.33; $E = 1.215, 1.207$. Each of these two potentials is correct if the activity of the hydroxide ion is taken equal to the molality of the base in the saturated solution. Actually, however, in such highly concentrated solutions, not only is the activity coefficient of the hydroxide ion unknown, but the activity of the water becomes important in the calculation. While an estimation of the activity coefficient of the water can be made from available vapor pressure lowerings of the concentrated alkali solutions, data from which activity coefficients of

hydroxide ion could be calculated are entirely lacking. Accordingly, what is above tacitly assumed in the calculations is that the ratio of the activity of the hydroxide ion and the water is unity. The assumption is justified by the results of the following paragraph.

In Figure 3 the polarization potentials of a cathodically protected pipe line are plotted as ordinates against associated driving voltages. The data have not been corrected for IR drops in the soil. However no polarization potential plotted in the figure exceeds 1.22 volts. Many similar groups of data show that the indicated upper limit of the polarization potential is never exceeded. These data thus demonstrate that the pipe line behaves like a hydrogen electrode at least at high current densities.

In a similar manner the polarization potential at incipient precipitation of calcium hydroxide can be calculated. This potential is of some interest because of the protective scale which forms on the surface of a pipe under cathodic protection.

Polarization of Copper Sulfate Electrode

In Figure 4 are shown readings of pipe line potentials with reference to a copper sulfate electrode taken with a multi-range voltmeter having an internal resistance of 1000 ohms per volt. At full scale the current through the instrument and the electrode is one milliamper. Therefore if the current is read at various voltage settings which in this instrument ranged from 20 millivolts to 20 volts, and the data are plotted as in the figure, the resistance of the electrode may be calculated from the resulting straight line (658 ohms in this case). When polarization occurs the curve will depart materially from linearity. Curves of this type have been discussed previously by the author¹.

Figure 4 shows that polarization began between .9 and 1.0 milliamper. With the potentiometers and high resistance voltmeters used in the field by corrosion engineers, current through the instrument as high as one milliamper is never encountered and is usually of the order of a few microamperes. Therefore it can be safely concluded that polarization of the electrode of the type under consideration is of no practical importance. This is contrary to general belief.

Extrapolation of the curve of Figure 4 to zero current intercepts the ordinate at a pipe potential agreeing with that measured directly with a potentiometer.

The electrode which yielded the data shown in the figure had been in service for several years before the measurements were made.

The author believes the electrode is more stable if it is deliberately polarized by allowing it to stand shorted to a buried iron structure an hour or so before use. The chemical reaction which occurs in the electrode when it is used to measure pipe potentials is the plating out of copper from the copper sulfate solution. Thus shorting the electrode for awhile produces a fresh copper surface upon which further deposition readily occurs when measurements are made. The lower end of the copper rod should be in contact with copper sulfate crystals and the electrode should be inverted once or twice before a reading is made to ensure uniformity in temperature and to prevent on cooling deposition of large crystals on the electrode.

Temperature Coefficient of Voltage

On six electrodes later to be discussed, tests were run to measure the temperature coefficient of the electrodes under field conditions. Ewing gave a curve showing the change in potential in millivolts with temperature in degrees Centigrade. From this chart the temperature coefficient can be taken as 0.9 millivolt per degree Centigrade (0.5 millivolt per degree Fahrenheit) in the range from zero to 50°C . This coefficient is given by Uhlig (Page 1137).

In Figure 5 are shown tests on two groups of electrodes in the approximate range from 40°F to 120°F . The upper limiting curve shows the results obtained with Electrodes 21, 23 and 25, and the two lower limiting curves for Electrodes 22, 24 and 26. Electrodes 21, 23 and 25 were first chilled in a refrigerator and then used to measure the potential of a structure with respect to adjacent soil. Readings were made constantly as the temperature rose toward that indicated by the short line perpendicular to the curve. When these electrodes reached this point at approximate atmospheric temperature they were placed in an oven and carefully heated to a temperature of about 120°F and then replaced in the soil and the structure potential measured repeatedly while the electrodes cooled.

Similarly, Electrodes 22, 24 and 26 were first heated in an oven. In this case the temperature exceeded 120°F . The plastic tube of one electrode was deformed by the heat. After the elec-

trodes had cooled they were chilled in a refrigerator and allowed to warm to atmospheric temperature. Meanwhile the potential readings were taken constantly. The slopes of the three curves as drawn are equivalent to approximately 54 millivolts over the 100 F temperature range. Thus the temperature coefficient, in close agreement with Ewing, is approximately .5 millivolt per degree Fahrenheit—a most fortunate value since corrections to 77 F can so easily and quickly be computed.

There are two surprising features evident in the diagram. The first is the apparent indifference of the potential of Electrode 22 to a change in temperature as the electrode warmed up. The author has no explanation for this peculiar behavior of the one electrode. A similar indifference has been recorded for a cooling electrode. In all such cases solid copper sulfate adhering to the working surface of the electrode was noted. The effect is probably related to the hysteresis against which Uhlig cautioned. Secondly, for the B-Group, there is a distinct shift in the two curves which do not coincide as they do for Curve 1, where the data for cooling and warming electrodes fall essentially on the same curve.

Between 50 C and 60 C (122 F to 140 F) hydrated copper sulfate undergoes a change in structure from an alpha form to a beta modification. The transition begins at about 120 F. It is the transition from the one form to the other that is thought to account for the displacement in the curve as the electrodes cooled from the higher temperatures. After the electrodes were chilled, a partial recovery or re-transition of the beta to the alpha form occurred so that the potential approached more nearly that of the first or upper group of electrodes. It appears from these data that the transition from one modification to the other is a fairly slow process. That the electrodes completely recovered is shown in data presented later. What the potential shift might have been had the transition upon prolonged heating become more complete has not been determined. This is a problem more appropriate for the laboratory.

It is clear from the data in Figure 5 that the electrode responds quickly to changes in temperature since the temperature coefficient determined in this practical way is the same as more precise laboratory measurements. Thus with reasonable precaution in checking the voltage before taking readings, to weed out electrodes like No. 22, in keeping solid salt in the electrode chamber, shaking before reading and preventing the electrode from becoming heated above 120 F, errors due to temperature and concentration changes can be minimized.

Reproducibility and Stability

Many electrodes have been studied with respect to their reproducibility and stability. In Table 2 are shown some measurements on the electrodes of Figures 1 and 6. The potentials of two structures, an iron stake and a water pipe, were measured to ensure that the potential of the structure did not change during the course of the tests. The data for the iron stake are not given since its potential was not constant. In the table the potentials have been corrected to 25 C in accordance with the conclusion of the previous paragraph.

Also given is the average electrode temperature as read on the individual thermometers (see Figure 1) and the atmospheric temperature.

Electrodes numbered 34 and 35 are not of the type shown in Figure 1. On past occasions with no commercial electrodes on hand, the author has used a crystal of copper sulfate with a copper wire tightly wrapped about it and enclosed in filter paper as an emergency reference electrode. To test whether such simple homemade electrodes can be used satisfactorily, many improvised electrodes have been made and tested. Electrodes 34 and 35 and an additional somewhat more complex electrode, as well as parts of the electrode of Figure 1, are shown in Figure 6.

The electrode within the coil of wire in the center of Figure 6 is intended to be buried adjacent to an underground structure and thus to serve as a reference in inaccessible places for a substantial period of time. It is composed essentially of a piece of copper surrounded by copper sulfate crystals embedded and sealed in a cylinder of plaster of paris. Electrode 34 was made by enclosing a piece of copper wire tightly wrapped about a large copper sulfate crystal between four plastic Band-Aids. Electrode 35 consists of an insulated No. 16 stranded copper wire bared about four inches on the end and inserted into a flex straw (such as is used in ice cream parlors). A thread of copper wire is wound tightly about the upper end of the straw to prevent leakage and is then covered with friction tape. The straw is filled with small copper sulfate crystals and the open end plugged with a 12-ply 2-inch x 2-inch sterilized gauze pad. The electrode when being readied for use should be filled with warm copper sulfate solution, with the gauze being inserted in the end of the straw. The electrode then should be allowed to soak in a solution of copper sulfate for a few minutes before use.

The Twenty series of electrodes in the table were made up in different ways. Numbers 22 to 24 inclusive were new electrodes which had never been used before. Electrodes 25 and 26 were old electrodes which had seen much service. The copper rods of the first five of these electrodes were polished. The rod of number 26 was corroded and coated with copper oxide and crystals of copper sulfate. It was made up with tap water. Chemically pure copper sulfate was used on four electrodes, with the commercial salt being used in numbers 23 and 24. Distilled water was used on Electrodes 21 and 25. A drop of nitric acid to prevent the formation of cuprous ion and the oxides was added to Electrodes 21, 22 and 24. Tap water having a resistivity of approximately 1000 ohm centimeters was used in Electrodes 23 and 26. The solutions in these electrodes were frothy from formation of a white precipitate. The external area of Electrode 25 was covered with aluminum foil to reflect sunlight. Except for these differences the electrodes were identical.

None of the variables described above appear clearly to have influenced the measured potentials reported in the table. It is surprising and generally in line with Hall that the two aged electrodes (25 and 26) which survived the tests were in good agreement with the average. Whether acid is added does not seem to make any difference; whether

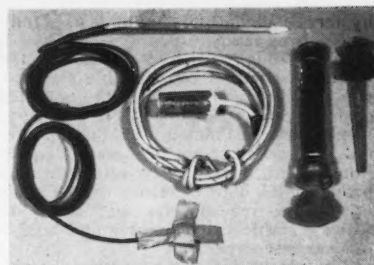


Figure 6—Components of the copper sulfate electrode (copper rod with cap, aluminum shielded plastic barrel and wood plug) are pictured at right. Also shown is a direct burial electrode, band-aid reference and flex-straw probe.

TABLE 1—Standard Electrode Potentials and Other Data for Metals

Metal	E°	m	Gamma	E(MSO ₄ , sat.)
Copper.....	-0.337	1.408	0.039	-0.300
Cadmium.....	0.403	3.683	0.043	0.426
Zinc.....	0.763	3.588	0.044	0.786

distilled water is used instead of highly conducting tap water does not make any difference; whether commercial or CP copper sulfate is used does not appear to cause a variation.

The electrodes were arranged in a semi-circle about the iron stake. Changing their relative positions did not have any marked effect on the potential. Wetting the electrode pockets in the soil with tap water, distilled water or a saturated copper sulfate solution did not change the potential.

The potentials in Table 2 were recorded generally over a three to four-day period. Unlike the iron stake, the potential of the water pipe remained constant during the test. Three of the commercial electrodes and the flex straw electrode proved satisfactory. Three of the electrodes leaked and a fourth one was distorted by temperature and was abandoned. Electrode 22 on recharging after the temperature tests was in agreement with the others until it was abandoned.

The satisfactory electrodes are in fair agreement.

Electrode	Median (millivolts)	Range (millivolts)
21	646	6
25	645.5	6.5
26	640	3
35	639	5

The range of the medians is 7 millivolts. The extreme range for all the data is 14 millivolts. The potential of the water pipe is probably 642.5 mv plus or minus 3.5 millivolts. This conclusion is in agreement with Hall who states that the electrode is reproducible within 5 millivolts.

The potentials displayed in Figure 5 were reduced to 25 C (77 F) by the coefficient of one-half millivolt per degree Fahrenheit which they, the data, determine. These reduced data are given in Table 3 together with related information. The range of the corrected data, except for Electrode 22, is very nearly within the reading error of the instrument scale which is plus or minus two millivolts. These data and the original measurement shown in Figure 5 are contrary to Uhlig (Page 1137) who says of the copper sulfate electrode "The E of this electrode is subject to pronounced

hysteresis effects and should be used only at constant temperature."

Even though with reasonable care the electrode exhibits considerable stability, some ready means to check the potential of the electrode in the field is needed since some electrodes may not exhibit a potential in agreement with others. If conditions permit, a flex straw reference may prove useful. This electrode can be made up within five minutes and seems to reach a stable value quickly and hold it over extended periods.

The electrodes are relatively insensitive to contamination as can be deduced from Figure 2 and Equation 4. However, they cannot be used satisfactorily for long in sea water, for example, where the influx of much chloride ion would seriously affect the electrode potential. If a small amount of chloride is added to the electrode, the electrode changes negligibly in potential, but if considerable salt is added, the blue color of the copper sulfate changes to green, showing the formation of cupric chloride which manifestly disturbs the activity coefficient of the copper ion and alters greatly the potential of the electrode.

Electrodes 25 and 35 were shielded from light but there is nothing in the performance of these electrodes to suggest any important effect of the light. The reflecting shield of Electrode 22 was effective in maintaining a more uniform temperature.

One source of error in copper sulfate electrode readings is the potential at the junction between the plug and the soil. These potentials which arise from concentration and other differences may reach objectionable values under certain conditions. Dry, porous, sandy soils may show as much as 20 millivolts variation in potential if water is added to the sand about the porous plug. If a small circular hole is dug in the ground to accommodate the electrode plug and this hole is filled if necessary with a clayey soil to hold liquid and then saturated with copper sulfate solution, the potential remains constant and is reproducible. A strong solution of sodium chloride also can be used but it is better to avoid possible contamination of the electrode by the salt. In the tests in Table 2 which were made on soil which had been recently moistened by rain, efforts to alter the potential by addition of salt solutions failed. The maximum change in potential was negligible.

Summary

For practical purposes the discussion and conclusions above may be summarized and expanded as follows:

- (1) It is well to keep track of the electrode in use by numbering all electrodes.
- (2) For ordinary measurements, polarization is of negligible concern.
- (3) It is not necessary that the copper rod be bright or freed of precipitated scale for reproducibility but it seems helpful to polarize the electrode before use.
- (4) To provide a clear solution it is well to use distilled water, CP copper sulfate and a drop of sulfuric acid (from an automobile storage battery if necessary) although these precautions do not seem important for stability.
- (5) There should be crystals of copper sulfate visible in the barrel of the electrode at all times to ensure saturation.
- (6) Means should be provided to check often the potential of an electrode in use. (This may be simply to compare

TABLE 2—Potential of Water Pipe at 25 C

Day	Hour	POTENTIAL OF ELECTRODES IN MILLIVOLTS								Average Cell Temp. (Degrees F)	Atmospheric Temp. (Degrees F)
		No. 21	No. 22	No. 23	No. 24	No. 25	No. 26	No. 34	No. 35		
1	1711	640	625	640	639	642	640	620	638	66	66
2	0742	647	Dry ¹	647 ¹	642	647 ¹	641	624	638	64	64
2	0928	646	639 ²	627 ²	643	641	638 ²	628	640	67	....
2	0940	644 ³	639	610	643 ³	640 ³	638	....	....	....	....
2	1028	642 ⁴	639	610	639 ⁴	639 ⁴	639	624	640	78	....
2	1100	641 ⁵	634 ⁵	610 ⁵	641 ⁵	640 ⁵	....	....	....	76	....
2	1544	652	....	654	....	651	....	630	640	70	70
3	0930	643	Dry ⁶	Dry	643	647	637	622	634	64	66
3	1106	648	644	....	646	649	642	....	....	69	69
3	1140	647	643	....	644	648	641	....	640	72	72
3	1620	645	640	....	643	645	643	....	638	67	....
4	0950	644	Dry	....	....	644	637	634	644	90	82
4	1110	644	....	....	....	642	642	630	640	77	83
34	1345	649	....	....	....	....	647	....	....	70	....
35	0918	647	....	....	....	....	....	....	....	67	67

¹ Cells 22, 23 and 25 recharged.

² Tap water added to soil at 22, 23 and 26.

³ Saturated Copper Sulfate added to soil at 21, 24 and 25.

⁴ Distilled water added to soil at 21, 24 and 25.

⁵ Temperature coefficient tests.

⁶ Cell number 22 recharged.

TABLE 3—Potential of Water Pipe at 25 C From Temperature Coefficient Tests

Group and Electrode	No. of Meas.	Time of Test, Hrs.	CELL TEMPERATURE		POTENTIAL		Mean Potential at 25 C	Range
			Initial	Final	Initial	Final		
B-22	8	1150	110	81	668	644	645.3	8
-24	8	to	117	82	666	646	643.3	5
-26	8	1241	110	82	662	646	643.9	2
A-21	7	1314	43	68	635	645	650.0	4
-23	7	to	43	68	634	648	651.9	2
-25	7	1353	46	68	636	646	650.4	3
A-21	9	1415	116	71	668	648	650.4	5
-23	9	to	116	70	675	650	653.6	3
-25	9	1500	114	70	674	648	652.4	5
B-22	8	1512	34	66	614	638	631.9	12
-24	8	to	38	66	625	648	645.9	4
-26	8	1617	42	66	628	650	647.4	4

COMPOSITE AVERAGES

GROUP	Average	Difference
A-21, 23, 25 (1).....	650.8	
A-21, 23, 25 (2).....	652.1	1.3
A-21 (2).....	651.5	
B-24, 25 (2).....	646.7	4.8
B-24, 25 (1).....	643.6	3.1

one electrode with another. Two electrodes should agree within 2 or 3 millivolts.)

(7) The electrode should be shielded from the sun to minimize changes in temperature; the thermometer should face away from the sun. Light does not seem to have an important effect on the potential.

(8) The temperature of the electrode should not be allowed to exceed 120 F when in use.

(9) Where precision is required several measurements should be made and averaged.

(10) Before a reading is made the electrode should be inverted once or twice to prevent in the long run precipitation of copper sulfate on the porous plug.

(11) Both the cell temperature and time of potential measurement should be recorded.

(12) All readings should be corrected to 25 C (77 F) using a positive tempera-

ture gradient of 0.5 mv per degree Fahrenheit.

(13) The potential of the copper: copper sulfate (saturated) half cell is -0.300 volts to the normal hydrogen electrode.

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Use of a Condensate-Corrosion Tester For the Survey of Return-Line Deterioration*

By A. A. BERK

Introduction

THOUSANDS OF area heating and power plants are operated by Federal agencies in this country and abroad. In some instances corrosion has caused costly losses of valves and piping in condensate return-line systems. In fact one of the defense agencies evaluated its maintenance costs from questionnaires and estimated that more than \$2,500,000 was spent during the first six months of 1955 for replacing and repairing such systems in its installations in continental United States.

Treatment with neutralizing amines was found to be a satisfactory method for controlling corrosion, proving especially effective for counteracting high carbonic acid concentrations in steam condensate. Other available chemicals are used to film the exposed metal to control corrosion. However, many of these methods of treatment are expensive, and the total cost of treating all Federal plants would be very high. Basing recommendations for treatment on local reports of trouble is unsatisfactory because some operators call attention to replacements of individual nipples while others regard severe corrosion as normal. Also, when treatment is begun after maintenance costs have become high, the system usually will be severely deteriorated before corrosion is controlled.

A screening test was needed to determine in which plants chemical treatment would be justifiable economically. The obvious need for determining the effectiveness of any method of treatment utilized for controlling corrosion stimulated interest in the development of a special tester for this purpose.

The first approach to meet this need was laboratory and field experimentation with the 3-coil tester of the National District Heating Association.¹ Correlation between the corrosion index derived from the weight losses of Bessemer-steel wire and the corrosion pattern on new test nipples was less than satisfactory. Testing with such devices as spools and strips suspended in condensate also gave little information on depth of corrosion penetration at the pipe wall and did not disclose whether carbonic acid, dissolved oxygen, and excessive flow rates were the principal factors causing corrosion. Thus, the test nipple appeared to be an essential part of any testing device to show the rate at which the condensate caused pitting, worming, or channeling of the piping. The Bureau of Mines condensate-corrosion tester is a composite test nipple designed on this basis.

Bureau of Mines Condensate-Corrosion Tester

The principal component of the Bureau tester (Figures 1 and 2) is the

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composite nipple, a set of 6 rings or shells that fit inside a specially machined 3/4-inch pipe nipple (other sizes have been used for special surveys). The rings are machined and precision-ground to a smooth finish. Inside diameter is 0.770 inch, with a tolerance of 0.001 inch, and outside diameter is 0.850 inch, with a tolerance of 0.0005 inch. The inner surface of the pipe nipple is similarly machined and ground so that the radial clearance between the rings and the enclosing pipe nipple is 0.001 inch or less. The nipple is three inches long and receives six 1/2-inch rings with square ends. The four center rings are marked, cleaned, and weighed before the composite nipple is assembled.

To protect the rings from crimping, as from the application of a pipe wrench to the composite nipple, the nipple is joined by couplings to end nipples of approximately the same internal diameter as the test rings. The open ends are capped to complete the tester for shipment. Each tester is identified by a number which is impressed on flats ground into the couplings.

All pipe fittings are of black steel or iron. The rings are not insulated from the shell or from each other. It was assumed that, owing to the square ends on the rings, essentially only the inner surface would be exposed to corrosion by the condensed steam. The two end rings are not considered test rings; they are provided primarily as retaining rings, serving also to shield the four central

Abstract

A description is given of a condensate-corrosion tester used by the Bureau of Mines to determine the economic advisability of chemically protecting condensate-return piping in various area heating plants. The tester is a composite test nipple with six rings fitting inside a specially machined pipe nipple. The average weight loss of the rings during exposure of the tester in a return-line system can be evaluated in terms of an average corrosion index. The tester also can prove useful in determining the extent to which chemical treatment has solved the corrosion problems involved, type of corrosion pattern present, factors responsible for the corrosion, etc.

More than 1000 testers have been issued to Federal heating plants and several hundred have been returned for evaluation of test results. Much has been learned toward improving operating practices in relation to corrosion control. Also, a much improved definition has been given to the conditions of effective use of chemical treatments for controlling return-line corrosion. The Bureau of Mines condensate-corrosion tester has been found to be a useful tool for an extensive survey at moderate cost.

2.4.2

rings from unusual effects of condensate flow and from the effects of the slight difference in potential between the black-steel shell and the seamless tubing (of approximately Bessemer-steel composition) from which the rings are cut. Each ring weighs approximately 6.5 grams and has an exposed test surface of about 1.2 square inches.

The cost of the tester may be of some interest. The pipe fittings (three nipples, two couplings, and two caps) are requisitioned from the Federal Supply Service at contract prices, and the current total per set is \$0.54. Machining costs are about 60 cents for the nipple and 30 cents for each ring. All but the composite nipple in returned testers is usually salvageable, and frequently the less corroded rings are used as end rings in new testers. Assembly time, including cleaning and weighing the rings, is about one hour.

Installation of Tester

The tester was designed to be installed after a trap draining an active hot-water generator or a unit heater of equivalent service. The preferred method of installation is to remove the caps from the tester and to insert it in a horizontal string of piping immediately beyond the trap. Usually, testers are placed at points where corrosion has been noticed. In installing a tester, the wrench is applied to the end nipples or couplings, never on the center nipple.

Because the principal factor in condensate corrosion is carbonic acid, maximum corrosion usually is found in the last building along the steam main. Steam loses heat as it flows through the mains, and some condensation takes place. Owing to its very low solubility in water at high temperatures, the carbon

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Figure 1—Bureau of Mines condensate-corrosion tester assembly.

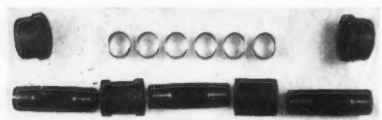


Figure 2—Component parts of tester.

dioxide in the steam does not condense in proportion to its concentration and therefore builds up in a steam from which condensation losses are appreciable. Thus, abnormal condensation in a branch steam main may increase condensate acidity and corrosion in any building in which the steam piping is poorly insulated. However, where the plant has no special trouble with condensate corrosion, the corrosion survey ordinarily will be made in the last building served by the steam main.

There is a second advantage in conducting the survey as far as possible along the steam main from the boiler plant. When chemical treatment is used, there is always some question as to whether or not the entire system is receiving adequate protection. It is reasonable to assume that the treatment is reaching the piping close to the boilers if there is no appreciable corrosion at the end of the system.

Tests lasting 60 to 90 days are recommended in plants having a history of corrosion trouble. Longer test periods of a full heating season are common in plants that have not reported high maintenance costs. Tests lasting 60 to 90 days are adequate for comparing the effectiveness of chemical treatment.

Most large Federal facilities have more than one heating plant. Although the raw water is usually uniform, there frequently are differences in various plants in feedwater treatment, boiler-feedwater makeup, and degree of deaeration. A survey includes the placing of testers in representative heating plants. Usually, not more than two testers are used in any one return-line system; also, it is assumed that low-pressure plants operated without makeup have no return-line corrosion problems (corrosion in such systems is usually traceable to poor lay-up practice during intervals between heating seasons).

A data sheet is provided with each tester, and records are kept of installation and removal dates, plant-operating conditions, fluid flows, temperatures, and similar pertinent information. Also, the operator provides a drawing showing how and where the tester was installed. The operating information on the data sheet is especially useful when the tester evaluation shows that a corrosion problem exists. Frequently, this information indicates to what extent improvement can be made by reducing steam and condensate losses or by changing the feedwater treatment; it also helps in the selection of a chemical treatment that will control the corrosion most economically.

At the end of the run the tester is removed from the pipe string, with care being taken that the wrench is not ap-

plied to the center nipple. The warm tester assembly is drained, shaken to remove drops, and capped. It and the completed data sheet are then returned to the Bureau's Industrial Water Laboratory for evaluation of the test results.

Tester Evaluation

Although the principal purpose of a corrosion survey is to determine whether or not a corrosion problem exists, other valuable information frequently can be obtained. For this reason, the tester evaluation goes considerably beyond the fundamental requirement of determining weight losses and calculating corresponding corrosion indices. An attempt is made from initial superficial examination, plus spot testing of deposits with mineral acid, to determine the tendency of the corrosion product to decrease the rate of pipe deterioration. The cleaned test surfaces also are examined carefully for clues indicating the factors responsible for the corrosion.

When the tester is received, it is dismantled to the center composite nipple and one coupling. A description of the appearance of the corrosion products in the composite nipple is then recorded, and a qualitative test is made to determine the wettability of this oxide layer. The surface of one of the end rings is

then brought to focus under a low-power microscope and spotted with hydrochloric acid of 1 or 2 percent concentration to yield a qualitative measure of oxide penetrability by an active corrodent, in terms of time to the first appearance of hydrogen bubbles.

After this preliminary testing, the composite nipple is immersed in oil several hours to provide a lubricating film between the rings and the retaining nipple. The rings are removed in an arbor press. Although the outer surfaces of the rings are sometimes slightly notched during this process, loss of metal has not exceeded 3 milligrams in a large number of trials. In a few instances the rings were so thin that the retaining nipple had to be split so that they could be removed without additional damage. The four central rings are then freed from corrosion products by a ½-hour treatment with 5 percent acetic acid, inhibited with Rodine No. 41* at 140 F. Occasionally, it is necessary to repeat the oxide-stripping treatment until constant weight is attained (the loss of metal during the stripping

* American Chemical Paint Company, Ambler, Pennsylvania.

TABLE 1—Reproducibility of Weight Losses in Corrosion Testers

TESTER NO.	Ring No.	Original Weight, gm.	Final Weight, gm.	Loss, gm.
A-251	1	6.510	5.293	1.217
	2	6.542	5.410	1.132
	3	6.493	5.373	1.120
	4	6.562	5.392	1.170
	Average			1.160
A-621	1	6.507	5.726	0.781
	2	6.504	5.693	.811
	3	6.458	5.711	.747
	4	6.531	5.768	.763
	Average			0.775
N-1271	1	6.546	5.831	0.715
	2	6.582	5.876	.706
	3	6.558	5.862	.696
	4	6.593	5.932	.661
	Average			0.694
W-1471	1	6.683	4.389	2.294
	2	6.581	4.394	2.187
	3	6.630	4.460	2.170
	4	6.597	4.459	2.138
	Average			2.197
W-1621	1	6.628	6.246	0.382
	2	6.431	6.041	.390
	3	6.525	6.123	.402
	4	6.555	6.153	.402
	Average			0.394

TABLE 2—Specimen Tabulated Report

TESTER NO.	Period, days	Treatment	TEST RESULTS	
			Weight Loss, gm.	Corrosion Index ¹ , mils per year
A-1751	168 ²	None	0.073 ³	1
A-1761	167 ⁴	None	.075 ³	1
A-1771	171 ⁵	None	.028 ³	0.4

¹ Indicated average rate of pipe wall thinning in thousandths of an inch per year.

² In Building 1213 on Central Steam System 1292; estimated average flow of condensate through tester about 66 pounds per hour at estimated maximum temperature of 185F; boiler-feedwater makeup 12,000 pounds (about 14 percent of total steam produced).

³ Very light channeling.

⁴ In Building 121 on Laundry Steam System 120; estimated average flow of condensate through tester about 53 pounds per hour at estimated maximum temperature of 200F; boiler-feedwater makeup 2,361,000 pounds (about 14 percent of total steam produced).

⁵ In Building 1205 on Central Steam System 1292; estimated average flow of condensate through tester about 66 pounds per hour at estimated maximum temperature of 185F; boiler-feedwater makeup 12,494,000 pounds (about 14 percent of total steam produced).

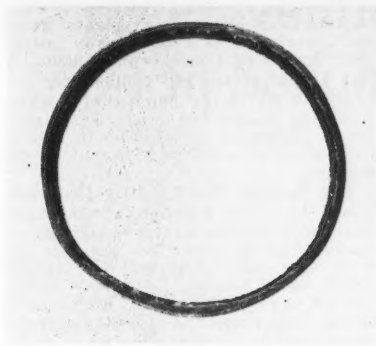


Figure 3—Pitting in Bureau of Mines tester ring.



Figure 4—Channeling in Bureau of Mines tester ring.

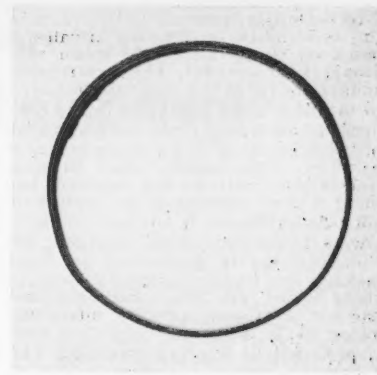


Figure 5—Nonconcentric thinning in Bureau of Mines tester ring.

treatment is about 1 milligram per ring on the average).

The cleaned rings are weighed, and the weight losses are averaged. In most instances the reproducibility is very good, as shown in Table 1. The corresponding corrosion index in thousandths of an inch per year is calculated from the average weight loss, using the formulas:

$$I = \frac{15,150 \times L}{W \times P}$$

where I = the corrosion index in mils per year

L = average weight loss

P = duration of run in days

W = average original weight of the rings

The formula is derived from the dimensions of the average test ring, assuming that corrosion penetrates uniformly and also that the penetration is small compared to the inside diameter of the rings (maximum error resulting from the second assumption is about 5 percent).

The test rings are examined further for the corrosion pattern in terms of pitting (Figure 3), channeling (Figure 4), worming, and surface roughness. Channeling is considered to be evidence of carbonic acid corrosion, and pitting is interpreted to indicate probable attack by dissolved oxygen. A special gauge, equipped with probe and dial indicator, is used to measure maximum penetration of corrosion. Worming and surface roughness may indicate corrosion resulting from both carbonic acid and dissolved oxygen, but frequently it also is associated with excessive rates of condensate flow. A lenticular corrosion pattern (broad shallow pits) suggests relatively small flow of certain types of contaminated condensate; a smooth test surface, off-center with respect to the outer circumference of the ring (Figure 5), has been found where corrosive condensate has been pumped through the tester at a very high velocity and pressure.

The findings from the examination of the tester are considered in relation to the entries on the data sheet. The positioning of the tester in the return system, the rate of flow of condensate through it, and the maximum temperature of the condensate flowing through the tester are all recorded as footnotes to the tabulated reports (Table 2). The corrosion index is variously interpreted, depending on the maximum penetration of corrosion and the duration of the run. It has been found that very short tests

(of about 30 days) invariably produce larger corrosion indices, owing to a tendency for the rate of corrosion to decrease with time. Accordingly, recommendations based on the reports are not always consistent with casual inspection, especially when the corrosion index is in a range in which the regions of very mild corrosion and essentially no corrosion overlap.

Survey Findings

Although the principal purpose of a survey with the Bureau of Mines condensate-corrosion tester is to determine whether or not chemical treatment is economically justifiable to protect the return lines of an area heating plant, other benefits of comparable importance have been derived from the test program. These include economies resulting from the review of plant practices and the demonstration in most instances that no treatment is required. Also, the corrosion pattern is frequently a useful guide to the chemical treatment most suited to a particular system.

In nearly every instance where the tester discloses a condensate-corrosion problem, the causative factor is carbonic acid in the steam condensate. The principal source of the acid is the free carbon dioxide and mineral carbonate contents of the makeup water. Most Federal facilities owe their relative immunity to return-line corrosion to the very low feedwater makeup characteristic of the operation of such plants. The first approach to the control of a corrosion problem, therefore, is an effort to decrease losses of steam and condensate by every practicable means. Similarly, several instances of troublesome corrosion have been traced to buildup of carbon dioxide content in the steam in poorly insulated mains and have been corrected accordingly.

In one defense agency it was found that most of the corrosion problem could be attributed directly to the carbon dioxide released in the boiler from the soda ash used in the boiler-feedwater treatment. The parallelism of soda-ash treatment and return-line corrosion was so striking that an agency directive ordered the use of sodium hydroxide in place of the soda ash to control alkalinity. The change in treatment, stemming directly from the corrosion survey, is expected to result in a savings of about \$1,000,000 a year in maintenance costs for this agency.

Other methods are available for excluding or removing corrosive carbon

dioxide from the heating system. In some plants a condensate-corrosion problem has been the deciding factor in favor of external treatment with a Zeo-Karb hydrogen-sodium system, in which a large proportion of the makeup water is passed through an acid-regenerated cation exchanger and a relatively small amount is softened in a conventional zeolite system. A degassing tower removes most of the carbon dioxide, and the pH of the combined effluent from the system is controlled by proportioning the flow to the acid- and salt-regenerated exchangers. Part of the carbon dioxide may be removed in other external softeners, such as lime-soda, hot-lime phosphate, hot-lime zeolite, and chloride-regenerated anion exchangers. Improved operation of available deaerating equipment frequently results in the removal of increased quantities of carbon dioxide at the deaerator vent, and proper trap and flash-tank maintenance often improves the purging of carbon dioxide from the return-line system.

When the tester shows that there is no corrosion problem at a particular facility, the immediate effect is frequently a considerable saving. Most plant superintendents have received many visits from salesmen of feedwater treatments who have painted disturbing pictures of deteriorated piping and plants operating under extreme difficulty owing to loss of condensate returns. Considerable pressure is thus exerted to apply chemical treatment, usually of a proprietary nature. Accordingly, the assurance that a plant is not being deteriorated rapidly has resulted in important total savings from withholding treatment or even discontinuing treatment at plants where chemical treatment was not needed.

Evaluation of Chemical Treatment

The neutralizing amines, cyclohexylamine and morpholine, and the filming amine, octadecylamine (often in the form of octadecylamine acetate) are the chemicals most frequently used for controlling corrosion in condensate-return systems. The former leave the boiler with the steam and are sufficiently alkaline to neutralize the carbonic acid in the condensate. The filming amine is either steam-distilled from the boiler water or is added directly to the steam in sufficient quantity to form a continuous water-repellent film over the surfaces of the pipe through which the condensate flows.

The dosage of a filming amine, about

2 or 3 ppm, is relatively independent of the condensate quality and usually is based on the quantity of steam produced. In contrast, the neutralizing amines are fed in the quantities required to maintain slight alkalinity in the condensate; accordingly, the concentrations of these chemicals in the steam are comparatively high, usually about 50 ppm. Neutralizing amines are recycled, but there is some question as to whether or not octadecylamine is affected similarly. Owing to its exceptional volatility, cyclohexylamine is preferred in low-make-up, low-pressure heating systems to about 50 psi. The less volatile morpholine has a greater recycling advantage owing to its lower alkalinity¹ and thus is preferred at higher pressures. The amines are lost from the system with wasted steam and condensate; in addition, appreciable quantities of morpholine may be lost with blowdown.

The principal factors determining the treatment to be prescribed for a particular plant are the feedwater-make-up rates and the free and combined carbon dioxide content of the makeup. Owing to the comparatively fixed dosage required for filming treatment, it is relatively simple to estimate the comparative economy of using a neutralizing amine in a system of known condensate loss and blowdown. A makeup rate of 20 percent or less almost always leads to a choice of a neutralizing amine. In the relatively few plants where makeup is 30 percent or higher, the choice is frequently octadecylamine or octadecylamine acetate. The plant is then given the option of feeding octadecylamine to the steam or octadecylamine acetate to the feedwater.

Dissolved-oxygen corrosion may influence the choice of treatment where other factors are nearly equal, assuming that the filmed steel will resist this type of deterioration. However, it has been found that equally good control is effected with neutralizing amines when the amine makeup is geared to a somewhat higher condensate alkalinity obtainable by increasing dosage by about 15 percent. Therefore, in the relatively few instances in which severe pitting has been found in low-pressure, low-make-up systems, the usual method of control is to increase the cyclohexylamine-carbon dioxide ratio in the condensate until the pH is 9.

Tester evaluation of neutralizing-amine treatments has with one exception shown the treatments to be uniformly satisfactory. The exception was the treatment in a Midwestern heating plant operated at 40 psi, where morpholine makeup was added at the very inadequate rate of ½ pound per million

pounds of steam; the feedwater-make-up rate was about 20 percent of the steam produced, and the raw-water alkalinity was relatively high. The Bureau recommended that the plant decrease its steam and condensate losses and use cyclohexylamine in doses that would provide a slightly alkaline condensate. This treatment was to be evaluated with a second tester.

Results using octadecylamine and octadecylamine acetate have not been consistent. Twenty-seven testers were submitted for evaluation during fiscal year 1956 after being used in tests to show the effectiveness of filming treatments. In 13 instances the corrosion index was 5 or higher, and the tester rings frequently were either wormed or pitted. Several of these tests were discounted because the tester was poorly positioned and received heavier condensate flow than is ordinarily recommended for ¾-inch pipe; such positioning was considered to make for erosion and exceptionally poor film stability. In a few other instances the reason for the poor results was obvious in that the dosage of octadecylamine or octadecylamine acetate was considerably less than that usually required for corrosion control.

The findings do not appear to favor either octadecylamine or octadecylamine acetate. In most instances the survey at these plants was begun after the filming treatment had been in use a year or more, and there is no apparent reason for the unsatisfactory results shown by the corrosion testers. Unfortunately, very little is known about the distribution of the filming chemical in the heating system and the effect of condensate quality on film formation and stability. A project to obtain some of the missing information has been begun by the Bureau.

Summary and Conclusions

More than a thousand Bureau of Mines condensate-corrosion testers have been distributed to Federal heating and power plants for surveys of return-line corrosion. About 400 of these had been returned for evaluation when this paper was written. In most instances the tester was used to show whether or not a corrosion problem existed. At other plants the purpose was to evaluate the effectiveness of chemical treatment for controlling corrosion.

The tester is not inexpensive; however, total costs of a tester survey of the plants operated by Federal agencies are a very small fraction of total annual maintenance costs. Immediate savings result from withholding or discontinuing treatment at plants that have no cor-

rosion problem. Savings also are effected by providing chemical treatment of demonstrated effectiveness at plants where such treatment is economically justifiable. Improved housekeeping, including less loss of steam and condensate, in a comparatively large number of installations has made for more economical steam generation in addition to solving the corrosion problem indicated by the survey.

The findings show clearly that most plants have no condensate-corrosion problem, probably because the plants are operated at relatively low pressure and with very little makeup. The largest single factor causing return-line deterioration was a high carbonic acid content in the condensate due to a high percentage of boiler-feedwater makeup. Similarly, soda-ash treatment of the feedwater caused many of the corrosion problems that were disclosed by the tests.

Chemical treatment with neutralizing amines proved to be very dependable, as determined by the tester survey. Filming treatments were consistently much less effective; however very little is known about the distribution of such chemicals in relation to water quality, and no explanation can now be advanced for the relatively poor results.

The Bureau tester is a composite nipple and, as such, shows a corrosion pattern as well as an average loss of weight which may be translated into a corrosion index. It has been possible to correlate tester results with maintenance costs available at a defense agency, and the parallelism is good. Accordingly, the tester is considered to provide reliable information as to the need for chemical treatment in condensate-return systems.

Acknowledgments

Bureau personnel who performed the laboratory tests during the various stages of development of the Bureau of Mines condensate-corrosion tester include Joseph Nigon, Paul Goldberg, George Hopps, David Icenhower and Roy Wilfong. The manuscript was reviewed by Raymond Love and Robin Van Meter. Department of Defense employees who were especially helpful in developing field-test data include Eugene Congress, David Costello, Harold Pfreimer, and Walter Schoenian. The advice and encouragement of John F. Barkley are especially gratefully acknowledged.

Reference

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Any discussions of this article not published above
will appear in the June, 1958 issue

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Prevention of Localized Corrosion In Sulfuric Acid Handling Equipment*

By G. A. NELSON

Introduction

LOCALIZED CORROSION of steel in heat-affected areas, particularly adjacent to welds, has been a continuing problem in the handling of sulfuric acid. The corrosion is generally in the form of deeply etched grooves which may occur immediately adjacent to a weld or at distances from it of as much as two inches. The groove has smooth sides and usually is regular in its contour. Steel adjacent to the groove generally has a slightly higher corrosion rate than the body of the plate.

Examples of the forms in which grooves occur are shown on Figures 1, 2, and 3.

The presence of localized grooves by corrosion adjacent to welded areas was at first attributed to stresses created by welding. Pipe sections which had been stress-relieved at 1150 F after welding were then installed in the acid lines. After a short period of service, the grooves were again found to be present. As a result of this test, the theory that stresses were the cause of the corrosion was abandoned.

Literature References

In September of 1947, R. W. Manuel¹ presented a paper to the National Association of Corrosion Engineers entitled "The Effect of Carbide Structure on Corrosion Resistance of Steel." In this paper he attributed localized corrosion adjacent to the upset sections of oil well tubing to a spheroidized condition of the carbides. It was his contention that when the steel is in the normal pearlitic condition, the lamellae of normal pearlite tend to anchor the corrosion products to the surface area, whereas spheroidized carbides have no such action. The type of corrosion observed by Manuel is somewhat different from that noted in welded acid piping. Whereas the corrosion observed by Manuel in oil well tubing was in the form of irregular ring worm effects, the corrosion in acid piping is in the form of clear cut grooves.

In a paper by P. H. Cardwell² it was shown that in inhibited hydrochloric acid solutions, a difference in corrosion rates was experienced by steels when the crystal structures were different. The conclusion reached was that the more complete the annealing, as measured by the resolution of the pearlite, the lower the corrodibility. When there is a variation in the grain size, pitting occurs in the area of larger crystals. This may be due, in part, to the larger crystals, but what seems to be more important is the presence of two dissimilar metal structures.

The latter reference was not available in 1948 at the time the work reported in this paper was started. It is cited, however, inasmuch as it shows that acceler-



About
the
Author

G. A. NELSON—Staff metallurgist for Shell Development Co., Emeryville, Cal., he formerly was metallurgist with Shell's Pittsburg, Cal. ammonia plant. He worked for National Lead Company and American Smelting & Refining Company before joining Shell. Mr. Nelson attended Armour Institute, Lewis Institute and MIT. Among other activities he is a member of ASTM Committee A-1, secretary of the chemical and petroleum panel of the joint ASME-ASTM Committee on the Effect of Temperature on the Properties of Metals, and a member of ASM.



Figure 1—Welded 4-inch steel elbow in 65 percent sulfuric acid service. Localized corrosion is adjacent to welds.

ated corrosion in a metal can be caused by galvanic effects created by structural differences.

Plants Tests

A sample of a groove-corroded steel elbow was critically examined in investigating the possibility that differences in metal structures could have contributed to accelerated corrosion in acid piping. A partially spheroidized condition was found beneath the corroded areas in contrast to a normal pearlitic structure in the unaffected metal. Photomicrographs from these studies are shown on Figures 4 and 5.

As a result of the above findings, plant tests were undertaken to further study the possibilities of eliminating the corrosion.

Effect of Heat Treatment

The first test consisted of fabricating a welded stress-relieved pipe section and

Abstract

Accelerated corrosion in areas adjacent to welds in steel equipment handling sulfuric acid has been a problem in acid handling plants. The corrosion is usually in the form of deep grooves, which penetrate the steel at an advanced rate. This paper summarizes the results of field tests to determine the causes for the localized corrosion and to enumerate possible remedial measures. It appears that the corrosion is due to differences in carbide structure created during welding or hot riveting operations. Possible mitigative measures are to (1) remove the objectionable zones by a normalizing heat treatment, (2) prevent objectionable phases from forming, or (3) cover the areas with other corrosion resistant materials.

3.7.3

exposing it to service in the acid line. After three months it was found that grooves were present. A second piece was then installed which had been normalized after welding. After exposure to the acid for the same period of time the grooves were absent. Several full-length sections were then fabricated, normalized and exposed. These pipes attained a normal life without premature failure. The results of these tests confirmed previous findings that stress relieving in itself will not prevent groove corrosion. They showed also that accelerated corrosion can be eliminated by a heat treatment above the critical temperature to equalize the grain structure.

Effect of Carbide Structures as Affected by Corrosion

In order to determine to what extent carbide structures of steel might influence the corrosion rate, a series of test spools were installed in the acid line.

The steel pipe used for the tests was furnished by the Pittsburgh Steel Company.

Size of spools: 2-inch. Schedule 160 pipe by 30 inches long.

Material in spools: J55 oil well tubing.

Analysis of steel: C, 0.41; Mn, 0.98; P, 0.021; S, 0.038; Si, 0.19.

Material handled: 60-67 percent H_2SO_4 .

Temperature: 50 F.

Velocity: 1.2 ft/sec.

Pipe spools 30 inches long were obtained from one length of pipe. After sections representing the usual mill annealing practice were removed, other samples were subjected to heat treatments which produced a spheroidized structure in one set and a normalized condition in the other.

Two sets of pipe spools were installed. The first was equipped with gaskets and insulating bolts so as to prevent contact between sections, while the second set was installed in such a manner that electrical current could flow between the sections. After 96 days' exposure the corrosion rates given in Table 1 were observed. These data are shown graphically in Fig-

* Submitted for publication March 20, 1957.
A paper presented at the Thirteenth Annual Conference, National Association of Corrosion Engineers, St. Louis, Missouri, March 11-15, 1957.



Figure 2—Welded 4-inch steel elbow in 98 percent sulfuric acid service. Localized corrosion is adjacent to welds.

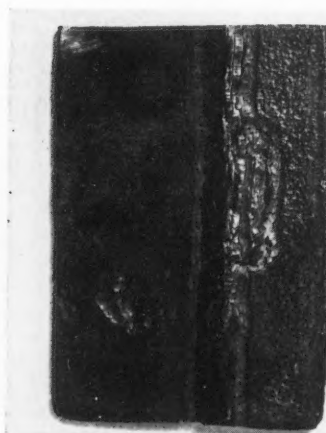


Figure 3—Welded steel storage tank in 65 percent sulfuric acid service. Localized corrosion is adjacent to weld.

ure 6. Using the corrosion rate for the regular mill annealed steel as unity, the relative corrosion rates for the other types of steel are compared by the heights of the crosshatched sections.

The figures and charts indicate that the spheroidized structure as such, may have a better corrosion resistance than the pearlitic structure and that the accelerated corrosion experienced in service may be due to galvanic effects.

As shown by the second set of figures, the indication is that when spheroidized steel is connected with ordinary steel, the spheroidized steel suffers a loss at a higher rate than normal steel.

The tests demonstrate that when spheroidized steel is connected to normal steel it corrodes at a higher rate than when it is insulated from that material. In view of the galvanic effect it is reasoned that if a narrow band of spheroidite is present adjacent to a weld and is anodic to the main body of the steel, it could readily be affected and thus lead to the formation of deep grooves. However, it had not been determined if the heat of welding on spheroidized steel would produce a zone in the heat affected area which would be susceptible to accelerated corrosion.

To clarify this point, pipe sections of spheroidized steel were welded to each other and also to sections of normal pipe. This pipe assembly was installed in the cold acid line. After four months in serv-

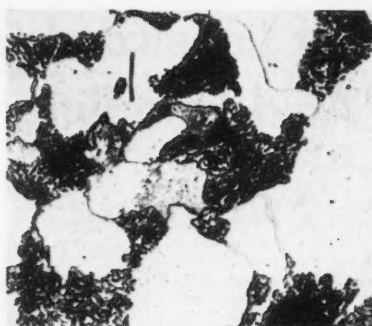


Figure 4—Bottom of shallow groove. Note fine spheroids in this detail shot of spheroidized pearlite grains. Original magnification, 1500X; actual magnification after reduction for engraving purposes, 800X. Nital etch.



Figure 5—Unaffected parent metal. Predominantly lamellar pearlite grains are shown. Original magnification, 1500X; actual magnification after reduction for engraving purposes, 800X. Nital etch.

TABLE 1—Corrosion Rates of Isolated and Coupled Steels

Condition of Steel	Isolated	Coupled
1—Regular.....	0.054"/yr.	.048"/yr.
2—Normalized.....	0.056"/yr.	.050"/yr.
3—Spheroidized.....	0.045"/yr.	.066"/yr.

ice it was withdrawn and examined. Grooves were found in all pieces of pipe. This demonstrates that grooving cannot be eliminated in welded equipment by using spheroidized steel. In addition to the finding of grooves in the welded spheroidized sections, it was again found that where the spheroidized pipe was welded to normalized pipe, the general corrosion rate of the spheroidized pipe was higher than the normalized pipe.

Galvanic Effects

Potential measurements taken during the course of these tests confirmed that the spheroidized specimens were anodic to the normalized and regular pipe spools. The open circuit potential between the spheroidized and regular spools was of the order of 100 millivolts.

Effect of Velocity

In order to study the effects of velocities on promoting groove corrosion, a test line was fabricated as shown in Figure 7. This consisted of 1½-inch, 2-inch, and 3-inch mild steel pipe welded together with parts thereof given various types of heat treatments. This test line was installed in a hot service location where mild steel would not be expected to give a long life. Normally, steel is used only in cold service handling 65 percent H₂SO₄, but the location of the test line at 105 C was chosen in order to develop information as rapidly as possible. After an operating time of 11 days a leak developed adjacent to a field weld on the 1½-inch pipe. After removal, the pipes were split longitudinally and measurements made of the wall thickness and depth of the grooves at various locations. These measurements also are shown in Figure 7.

Photographs were made of significant corrosion effects. Figure 8 shows grooves on both sides of a field-welded joint. The cross pattern in the center of the pipe shows the start and end of the weld on the opposite side.

Figure 9 shows the presence of grooves in a piece of 1½-inch pipe which had been torch-heated on the outside to a temperature of approximately 1650 F. This indi-

cates that localized heating in some instances is sufficient to create a sensitive condition adjacent to this area.

Figure 10 shows the appearance of grooves adjacent to a field weld. These grooves are absent in the area of a weld which has been normalized.

Figure 11 shows the appearance of grooves adjacent to a field-welded joint in 1½-inch pipe. This is included in the report to indicate the severity by which butt-welded pipe is affected in acid service. While seamless pipe had been specified for installation on this project the inadvertent installation of butt-weld pipe yields further evidence that this material should not be used in acid service.

The results of the test showing the effects of velocities in promoting groove corrosion are summarized in Figure 12. It is apparent that at low velocities the corrosion rate is increased as much as 70 percent, and at high velocities by possibly as much as 300 percent. It should be mentioned again that the corrosion rates in this test were obtained under conditions where steel ordinarily would not be used. For cold 65 percent sulfuric acid the corrosion rate for steel is about 0.025-inch per year in tanks and 0.050-inch per year in piping.

Micro-Examination

During the periods of testing, samples were examined microscopically and it was generally found that the spheroidized condition was not too clearly defined. In other words, in the areas where corrosion was most pronounced the structure beneath the grooves would be of a mixed structure; some pearlitic areas were partially broken down with some spheroidized particles showing, whereas other pearlitic areas had their normal appearance. The photomicrographs (Figures 4 and 5) illustrate that the spheroidizing is not as complete as might be expected from a true spheroidized anneal. Therefore, it may be reasoned that the slight galvanic effects are produced by very small differences in potential between a large number of spots in the steel structure.

Efforts to Mitigate Groove Corrosion

As the results of the testing were being produced, plant efforts to mitigate groove corrosion were being advanced. Several methods have now been tried or are under trial in order to make the equipment last somewhat longer than previously.

Piping

Elimination of groove corrosion in piping can be accomplished by normalizing the entire piece after it has been welded.

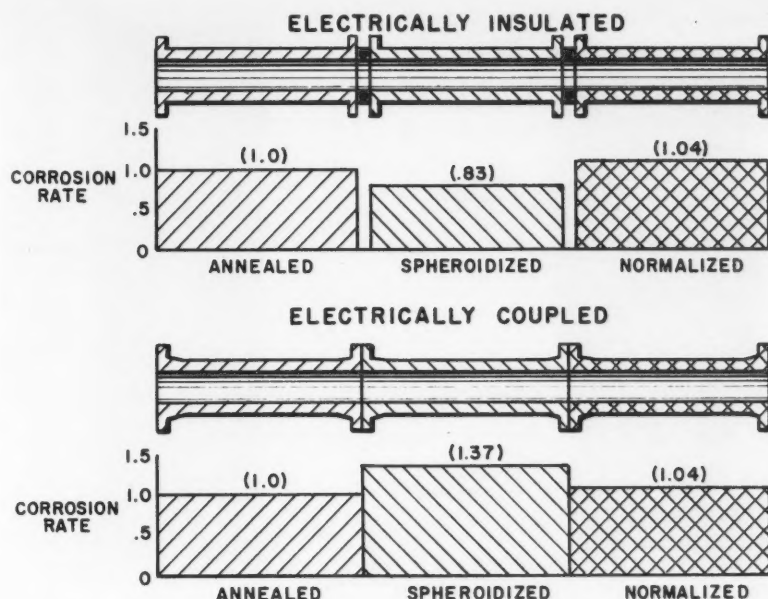


Figure 6—Corrosion rates in electrically insulated and electrically coupled pipe.

A local normalizing treatment at the welded ends is not adequate because of the gradual change in the structure that would result from the heat treatment. In other words, the groove effect would be located at the end of the heat run-out. Two methods other than the above could be used for stopping groove corrosion in piping.

- Roll pipe into flanges by mechanical methods.
- Use a slip-on flange and lightly seal weld the outer end of the flange to the pipe. The slight heat effect at that point probably would not be sufficient to create a spheroidized condition in the pipe proper.

Pressure Vessels

Welded steel pressure vessels can be normalized to provide protection from localized attack. Normalizing of pressure vessels presents an additional problem in that warping may occur while vessels are being heated at 1650 F. Tests were performed to determine the minimum temperature which would be necessary for removing undesirable structures. For these tests, welded test spools were normalized at 1550 F and 1450 F. After a test period in the acid line, it was found that the spool which had been normalized at 1550 F was entirely free from grooves whereas the sample normalized at 1450 F showed only a slight effect. It was concluded that a temperature of 1500 F would be suitable for normalizing of mild steel equipment which had been welded. Vessels normalized at this temperature are performing satisfactorily with no evidences of groove corrosion.

Storage Tanks

Fabrication of Welded Storage Tanks.

It has been found that groove corrosion in small parts can be eliminated by normalizing the entire piece. It is evident that such a treatment cannot be given large storage tanks. Another method for removal of the undesirable condition adjacent to welds in large tanks was tried. This

method was to withdraw the heat of welding as rapidly as possible and thus prevent the formation of spheroidized areas. It was reasoned that if the high temperature of the steel adjacent to a weld is not maintained for an appreciable length of time, the harmful spheroidized structure may not be able to form.

This idea was put to test when a new tank was erected by using the following technique. A light seal bead was welded on the inner course, with all subsequent welding being performed from the outside. Upon application of the second bead a water spray was applied to the inner bead. As the tank now had sufficient strength to hold water, it was gradually filled and all further welding was performed with a water level at least two inches above the weld seam. The cost of fabrication in this manner was approximately 10 percent higher than it would have been had the tank been fabricated by the usual methods (i.e., without chilling the weld).

The tank has been inspected three times. After the first inspection (approximately six months) the welds were free from groove corrosion with the exception of a few spots where ladders and clips had been welded on the outside by the contractor. These had not been chilled during welding. The inner surface of the tank opposite from these appurtenances showed a grooving effect.

A second inspection was made after 18 months' use and the same conditions were found to be present, with the exception that certain of the seal beads which had been made on the inner wall without chilling showed a slight but insignificant grooving condition adjacent to them. The third inspection after 29 months in service showed the condition of the tank to be approximately the same as found at the 18-month inspection.

The chill welding method was tried when other chemical plants came to require new storage tanks. An adaptation of the above method was used in some cases, in the belief that the heat of welding would be further removed by performing the seal bead on the outside. Once the initial seal

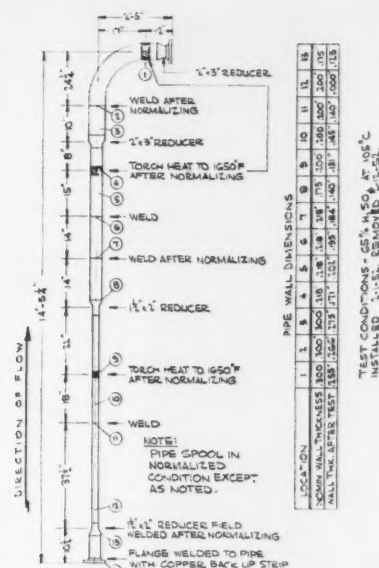


Figure 7—Welded steel line for velocity tests in sulfuric acid.

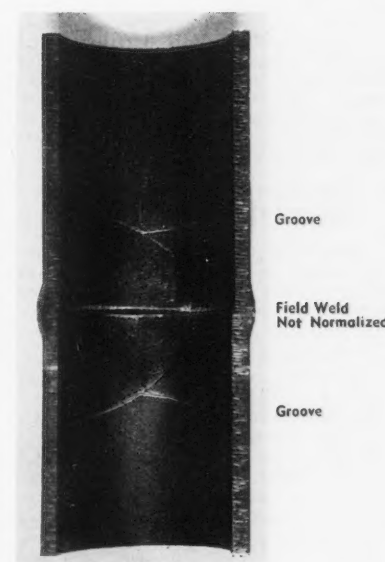


Figure 8—Two-inch schedule 80 test pipe in 65 percent sulfuric acid service. Temperature was 105 C (221 F).

bead had been installed, all subsequent welding was done from the inside of the tank while a water spray cascaded down the outside of the tanks. These tanks have been in service for approximately two years and have been found to be free of groove corrosion. During the progress of this welding technique it was found that a low hydrogen rod was needed in order to produce sound ductile welds. Once the welders had become accustomed to this technique they had no difficulty in producing welds which met all requirements of bend and tensile testing.

Both of the "chill welding" methods presented problems where the weld bead was affected. They also incurred higher fabricating costs and therefore are not being used at the present time.

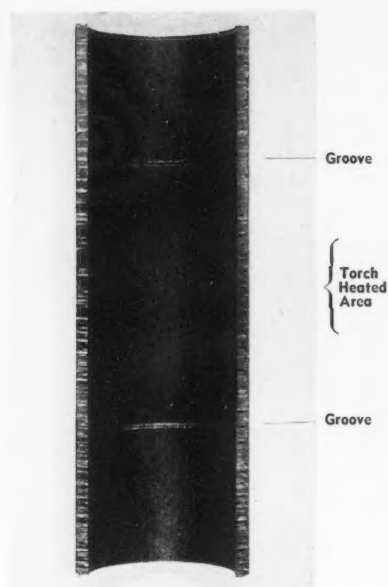


Figure 9—Test pipe in 65 percent sulfuric acid service. Pipe size was 1½-inch Schedule 80; temperature was 105 C (221 F).

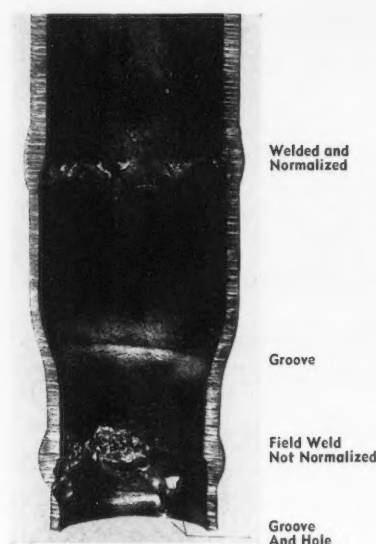


Figure 10—Test pipe in 65 percent sulfuric acid service. Pipe sizes was 2-inch Schedule 80 with reducer to 1½-inch Schedule 80; temperature was 105 C (211 F).

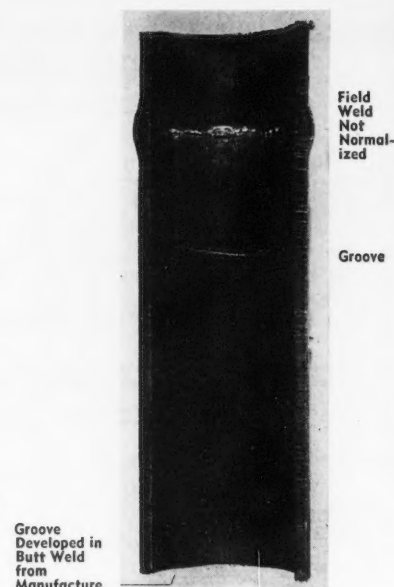


Figure 11—Test pipe in 65 percent sulfuric acid service. Pipe size was 1½-inch Schedule 80—butt welded; temperature was 105 C (221 F). Field Weld.

Other methods for protection of welds in storage tanks have been tested. Metal spraying of lead over the welded seam for protection of the sensitive areas has been unsuccessful, as the lead spalls off. Burning of lead over the seam appears to be satisfactory. This is being done on a new tank which had not been chill-welded.

Corrosives in Which Attack is Dependent on Micro-Structure of Steel

During the period of testing, a survey was started to enumerate the corrosives which promote this type of attack. These environments are as follows:

1. Hot sour oil lines at 700 F.
2. Phenol at 400 F.
3. Furfural with 8 percent water at 100–250 F.
4. Condensate wells containing CO₂ and water.
5. Sweet oil wells containing CO₂ and brine.
6. Strong caustic solution.
7. Contaminated water lines.
8. Sulfuric acid.

Conclusions

From the results of this investigation the following conclusions are drawn:

1. Carbon steel equipment operating in sulfuric acid service is subject to accelerated corrosion in heat-affected areas. These areas can be produced by such fabrication procedures as welding or hot bending.

2. The accelerated corrosion is due to galvanic action created by two different types of structures in contact with each other. It has been found that the carbide structure of the steel in grooved areas is spheroidal in character as contrasted to the normal pearlitic texture. The spheroidal condition also has been found to be anodic to the normal texture and could thus account for the accelerated attack.

3. The accelerated corrosion can be eliminated by removing undesirable zones.

Normalizing the entire piece after welding accomplishes this purpose. For equipment too large to be normalized, welding techniques to prevent the harmful zone from forming can be used. If neither of the above procedures can be followed, the sensitized areas can be protected by an overlay of a corrosion resistant metal such as lead. Tests of this method have been successful and no galvanic effects from the lead overlay were observed.

4. The accelerated corrosion cannot be eliminated by specifying spheroidized steel.

5. Groove corrosion is believed to be aggressive only in mildly corrosive service. Where corrosion rates are high it is expected that the general rate of thinning will be so great that the added effect of the groove will be of little consequence. Where corrosion rates are low it is anticipated that the galvanic effect will produce a deep groove which will cause equipment to be retired or repaired before its expected life has been attained.

6. Grooving corrosion near welds is accelerated by high velocities of the acid stream.

References

1. R. W. Manuel, *Corrosion*, 3, 415 (1947).
2. P. H. Cardwell, *Journal of the Electrochemical Society*, 101, No. 2, 84-90 (1954) Feb.

DISCUSSION

Question by G. Sorell, M. W. Kellogg Company, New York, New York:

Does this type of corrosion also appear in monoethanolamine service as you suspected some time ago?

Reply by G. A. Nelson:

Since finding this peculiar type of corrosion on steel in sulfuric acid service, we have endeavored to determine other environments which promote groove corrosion. Those found to date are enumerated in the text of the paper. Since writing the paper, the monoethanolamine plant re-

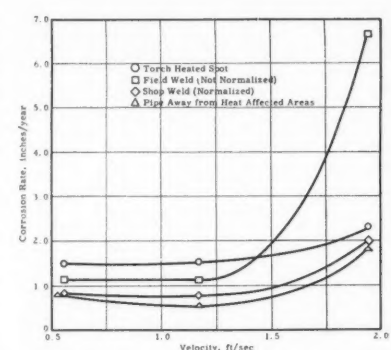


Figure 12—Effect of velocity on corrosion of steel in sulfuric acid service. Concentration was 65 percent sulfuric acid; temperature was 105 C (221 F).

ferred to by Mr. Sorell has been inspected and grooves were found adjacent to practically all the welds. It thus can be added to the list of corrosives which promote groove corrosion.

Question by Robert W. Manuel, New York, New York:

In some cases of corrosion of local areas of steel with spheroidized cementite predominant in the microstructure, galvanic effects appear to be ruled out by the high resistance of the corroding phase. For example, only a moisture film is present on the internal surfaces of tubing in gas condensate wells. Spheroidized structures would thus seem to be inherently less resistant in such a case and conversely, pearlite more resistant. Have you tried using medium carbon steel pipe for acid in order to take advantage of the greater amount of pearlite present compared with low carbon?

Reply by G. A. Nelson:

In reply to the first section of the comment concerning galvanic effects, the careful potential measurements made

between pipes with different structures indicate strongly that in sulfuric acid a galvanic action did exist.

As to the use of medium carbon steel pipe, these were used in one of the tests and as stated, contained 0.41 percent C. They were selected in order that a maximum amount of the different structures would be present and thus would enable a reasonable conclusion as to causes of groove corrosion. No medium carbon steel pipes have been used in commercial applications.

Question by William McGee, Granite City, Illinois:

Is it possible to successfully arrest the accelerated corrosion after it has begun by applying burnt-on lead?

Reply by G. A. Nelson:

Yes.

Question by Howard M. Randall, Amoco Chemical Corporation, Brownsville, Texas:

How can preferential corrosion an inch or so away from the weld be explained

when it is not usual for spheroidite to occur that far away from the weld?

Reply by G. A. Nelson:

Preferential corrosion does not always occur an inch from the weld. The distance is directly related to the heat that is retained by the steel. At the point where the maximum spheroidization is produced, the conditions for creating groove corrosion are satisfied. Sometimes the grooves are immediately adjacent to the weld. This is illustrated in Figure 3.

Any discussions of this article not published above
will appear in the June, 1958 issue

Study of the Compatibility of Floating-Type Inhibitors And Cathodic Protection*

By E. R. STREED

Introduction

CORROSION AND corrosion mitigation measures for fuel and ballast compartments of floating equipment has been the subject of considerable study by both government and private organizations.^{1,2,3,4} The immensity of this corrosion control problem has been encountered by the U. S. Navy's Bureau of Yards and Docks in the world-wide maintenance of ballast compartments of floating drydocks.

The interior of the compartments can be divided into three classification zones: (1) Submerged (permanently), (2) Intermittently submerged (dependent upon the water level during normal operation of the drydock), and (3) Non-submerged (above the normal high water level).

Corrosion is extensive throughout the interior of drydock compartments. Although no quantitative data are available on corrosion rates in the respective zones, visual inspection of interior stiffeners has indicated that the intermittently submerged and the non-submerged zones may actually suffer the most corrosion. Upper portions of tanker compartments carrying fuel and sea water ballast are more susceptible to rusting than the permanently submerged areas.⁵ Weakening and pitting of structural members and internal piping is a serious result of the corrosion.

The complex structure of the compartments and the poor accessibility of certain areas make proper surface cleaning and coating difficult, costly, and time-consuming. Therefore, to obviate the problems associated with manually-applied coatings, less costly and longer lasting methods of mitigation were investigated. Individual experimental applications of cathodic protection and floating-type inhibitors, in use for several years by the Bureau of Yards and Docks, have shown promising results. However, limitations inherent in each method do not always permit optimum protection of all areas of the compartments.

An investigation was undertaken to determine the compatibility and comparative effectiveness of floating-type organic inhibitors and cathodic protection techniques for sea water ballast compartments of floating drydocks.

Theoretical Considerations

The electrochemical corrosion of steel structures in a sea water environment or atmosphere has been extensively described.^{6,7} Other contributing factors such as structural stresses, metal composition, temperature, humidity and frequency and rate of liquid level changes may accelerate the corrosion rate.

Temperature extremes encountered by floating drydocks are typical of ambient conditions which vary from a low of about 0 F to a high of 120 F. While

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About the Author



ELMER R. STREED is a physicist with the U. S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California. He began employment in the Navy Department in 1940. After serving in the Navy from 1944 to 1946, he entered the University of Washington, graduating in 1950 with a BS in physics. His past experience includes three years in absorption and emission spectroscopy, and four years in the development and application of cathodic protection to floating drydocks.

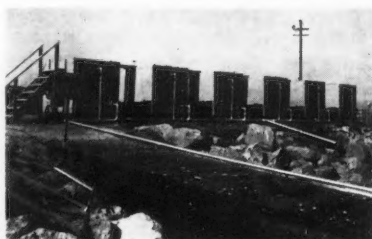


Figure 1—View of test facility. The 2½-inch line in the lower foreground leads to a 40,000 gallon per hour capacity pump, used for filling the pontoons. The individual filling lines, shown near the top center of each pontoon, extend down the side and come down to within 6 inches of the bottom of the pontoon.

higher temperatures usually encourage greater corrosion rates, these temperature extremes are not considered sufficiently great to interfere with the protective action of most good coatings or inhibitors.

Extreme humidity is typical of exposure in an enclosed vessel where there is sufficient water surface to maintain saturated conditions at all times. Condensation depends upon the rate and amount of temperature changes. Vernon has shown⁸ that incipient atmospheric corrosion effects began with a relative humidity of about 60 percent, and that a profound increase occurred at a relative humidity of approximately 80 percent, with the rate increasing until the dew point was reached. Dehumidification techniques, extensively used for storage and machinery compartments of active and reserve vessels, would not appear practical because of the constant

Abstract

Individual applications of floating-type inhibitors and cathodic protection for the corrosion mitigation of steel floating drydock ballast compartments have shown promising results in specific areas of the compartments. The theoretical considerations and results of simultaneous use of both methods in an experimental study are described.

After exposure for one year in a sea water environment, test coupon results indicate that a floating-type inhibitor can effectively retard corrosion in the intermittently submerged and non-submerged zones and will provide temporary protection in the wet zone. Cathodic protection, effective only on a submerged surface, achieved a 70 percent reduction in corrosion under severe exposure conditions. Cathodic currents were reduced by a factor of five when used with a floating inhibitor. No serious interference in the individual protective ability was detected when the two methods were used simultaneously. 8.9.5

existence of residual water in ballast tanks of floating drydocks.

Of the various available methods of corrosion protection (organic coatings, metallic coatings, cathodic protection, oil-soluble inhibitors, water-soluble inhibitors, and chemical-floating inhibitors) paint coatings have been relied upon principally until recent years. New coating developments have been made for interior tanks; for example, the development of a vinylidene chloride acrylonitrile copolymer (Saran) coating has been reported for fuel-resistant tank linings on naval vessels.²

Cathodic protection techniques can be used to mitigate corrosion on permanently submerged surfaces and the intermittently submerged zones receive protection approximately proportional to the amount of time submerged;⁴ therefore, a cathodic protection system must be justified primarily on the basis of corrosion reduction within areas below the normal, low water level. The fact that surface preparation is not necessary prior to installation and the relatively maintenance-free operation of a properly designed system are major factors in offsetting the high initial cost of cathodic protection. The choice of anode material, galvanic or inert, is dependent upon the accessibility of the area to be protected and the availability of external power.

Comprehensive reviews of the action of inhibitors have been published.^{9,10} Although corrosion mitigation with inhibitors is attributed to both physical adsorption and chemisorption, the exact mechanism for inhibition is still controversial. It is generally concluded that the inhibitor must function by increasing the electrolytic resistance, or polarizing either the anodic, the cathodic, or both areas of the corroding surface.

It is desirable to use an inhibitor which is relatively insoluble in water and which can be applied with a minimum of labor. Preliminary studies of chemical compounds used as floating cor-

rosion inhibitors have shown promise in six-month laboratory tests.¹⁰ These coatings usually consist of a petroleum vehicle with chemical additives which assist in displacing water from the metal surface and form a hydrophobic, protective film on the metal surface. The coating material is added to the ballast compartments in sufficient amounts to maintain a continuous floating film, and to recoat the metal surface as the ballast water level is changed. While the protective action of floating inhibitors usually is restricted to those areas which can be recoated through normal, water level changes, areas above and below can be coated initially by spraying or brushing. Periodic dewatering or filling to extreme levels will provide additional protection to areas not normally coated.

Test Facilities and Methods

A standard test procedure has been established for the evaluation of floating inhibitors (MIL-C-17936, Ships). However, the addition of cathodic protection with its associated current distribution system and the need for mounting duplicate sets of test coupons made it desirable to conduct a combined test in large tanks.

Standard Navy T6B, 1000-gallon pontoons with dimensions of 5 x 5 x 7 feet were used for the test facility. The pontoons, shown in Figure 1, were located on the shore of a sea water harbor and were equipped with a suitable piping and pumping system to simulate drydock ballast operations. By mounting on wooden dunnage and using plastic pipe nipples in the external piping, the pontoons were electrically insulated from each other.

The frequency and rate of water level changes vary considerably with the size and location of various drydocks; for convenience, a cycling period of two weeks was arbitrarily chosen. The pontoons were simultaneously filled with fresh sea water to the upper limit, 12 inches below the top of the pontoon, and allowed to remain full for one week. The water level was then drained simultaneously to the lower limit, 16 inches above the bottom of the pontoon, where it remained for an additional week. Filling and draining rates of approximately 1 1/4 inch-per-minute were used.

Commercially available floating inhibitors can generally be classified into two groups. The material, termed Type 1 in this report, is normally nongelling and is obtainable ready-mixed. The Type 2 material is a two-component product composed of an inhibitor and a diluent. The inhibitor gradually gels into a semi-solid coating which tends to build up on the metal surface. The diluent is added as required to maintain the viscosity of the residual floating material at a point low enough to permit the recoating of vertical surfaces.

Since it was desirable to determine both the efficiency and the compatibility of two types of inhibitors with two types of cathodic protection systems, a test facility comprised of six pontoons was employed as listed below.

Pontoon No.	Description
1	Type 1 inhibitor only.
2	One 1 1/2 x 60 inch Duriron anode.
3	One 4 x 40 inch graphite anode and Type 1 inhibitor.
4	One 4 x 40 inch graphite anode and Type 2 inhibitor.

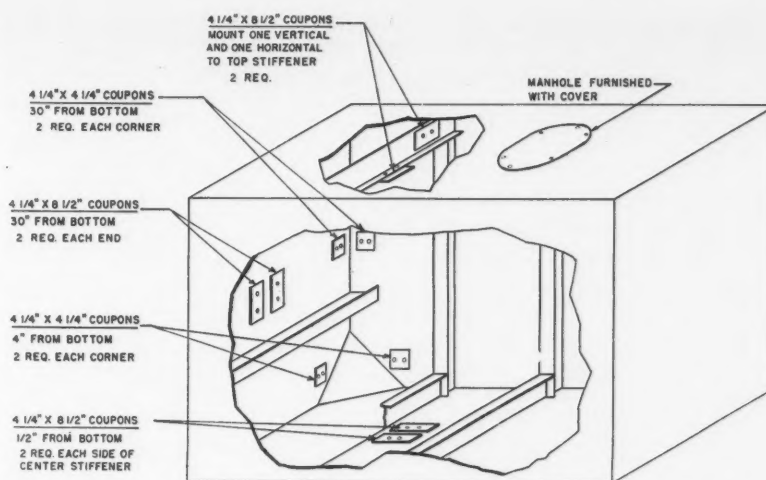


Figure 2—Cutaway of T6B pontoon showing location of test coupons.

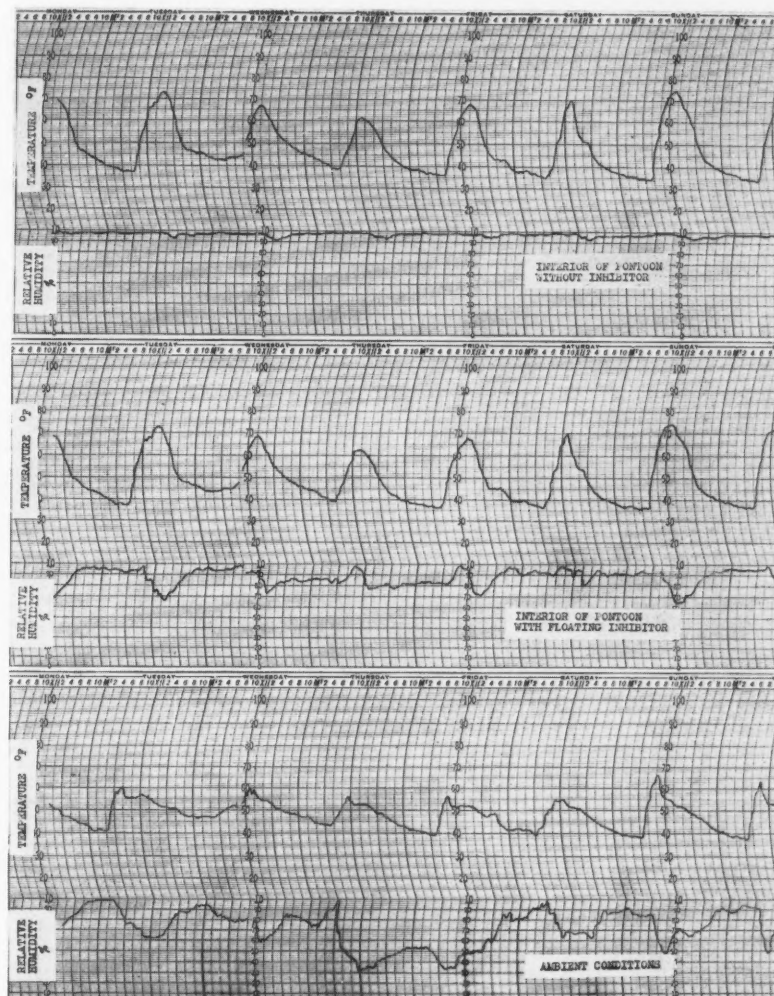


Figure 3—An illustration of the difference in the interior relative humidity of the test pontoons with and without floating inhibitor.

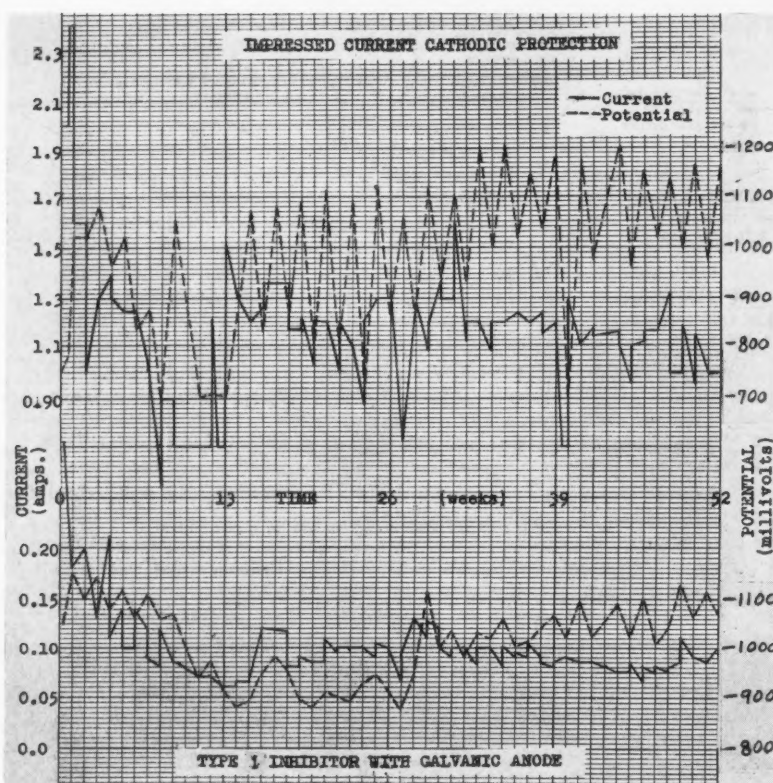


Figure 4—Potential and current data for impressed current cathodic protection and for Type 1 inhibitor with a galvanic anode.

TABLE 1—Corrosion Rates of Test Coupons in Various Exposure Zones

EXPOSURE	Submerged Zone		Intermittently Submerged Zone		Non-Submerged Zone	
	Average Loss (mpy)*	Reduction in Corrosion Rate (%)	Average Loss (mpy)	Reduction in Corrosion Rate (%)	Average Loss (mpy)	Reduction in Corrosion Rate (%)
Sea Water (control).....	3.0	0	8.14	0	7.02	0
Cathodic Protection.....	0.839	72.2	5.33	34.5	7.02	0.0
Type 1 Inhibitor.....	0.411	86.3	0.151	97.2	0.108	98.5
Type 1 Inhibitor with Cathodic Protection.....	0.088	97.1	0.122	98.4	**	**
Type 2 Inhibitor.....	0.325	89.1	0.108	98.7	0.028	99.7
Type 2 Inhibitor with Cathodic Protection.....	0.093	97.0	0.147	97.3	**	**

* Mills per year penetration (inches per year multiplied by 10^{-3}).

** No data obtained.

TABLE 2—Corrosion Rates of Vertically and Horizontally Mounted Test Coupons Located in the Submerged Zone

EXPOSURE	VERTICAL		HORIZONTAL	
	Average Loss (mpy)*	Reduction in Corrosion Rate (%)	Average Loss (mpy)	Reduction in Corrosion Rate (%)
Sea Water.....	3.37	0	2.27	0
Cathodic Protection.....	0.994	73.3	0.685	69.8
Type 1 Inhibitor.....	0.83	77.7	0.115	94.4
Type 1 Inhibitor with Cathodic Protection.....	0.121	96.7	0.056	97.6
Type 2 Inhibitor.....	0.586	84.4	0.071	96.4
Type 2 Inhibitor with Cathodic Protection.....	0.159	95.7	0.028	98.7

* Mills per year penetration (inches per year multiplied by 10^{-3}).

- 5 Five 15-lb. magnesium anodes and Type 1 inhibitor.
- 6 Type 2 inhibitor only.

A selenium rectifier power supply furnished the current for the passive anodes and suitable rheostats were incorporated in all anode leads for current control. All anodes were mounted horizontally on $\frac{1}{2}$ -inch studs welded to the bottom stiffeners of the pontoon and insulated from the studs with phenolic resin-laminated sleeves. An external lead was soldered to a washer bolted to the pipe core of the magnesium anodes and the connection-area was filled with an oil-insoluble potting compound. Five magnesium anodes were originally installed to ensure adequate current distribution. The bottom of each anode was approximately eleven inches from the bottom of the pontoon and was in the permanently submerged zone.

Because of the shielded areas under the stiffeners and in the pontoon corners, a potential of 1.00 volt (negative with respect to a copper sulfate reference cell) at the high water level, was considered desirable. All potential readings were measured on a weekly schedule, with a potentiometer-voltmeter, before the water level was changed. To avoid contamination of the half cell porous plug by the floating inhibitor, a floating well was constructed from a balsa wood float with a plastic pipe 4 inches long and 2 inches in diameter extending through the center. All inhibitor was removed from the interior of the pipe, and the half cell was lowered into the sea water through the pipe.

The effectiveness of the two methods of corrosion mitigation was determined by the use of preweighed, $\frac{1}{4}$ -inch thick, mild steel test coupons. The coupons were sandblasted and mounted, as shown in Figure 2, in each of the three exposure zones. Two coupons, one of which was electrically insulated, were bolted at each location in the pontoons under cathodic protection. Insulated test coupons located in Pontoon No. 2, containing no inhibitor, were used as controls for determining the corrosion rate of unprotected coupons.

The interiors of the pontoons were initially covered with a thin coating of rust on about 25 percent of the surface area and mill scale on the remaining area. After the test coupons were installed, approximately $2\frac{1}{2}$ gallons of floating inhibitor were applied to all surfaces of the proper pontoon with standard paint-spray equipment. Sea water was then slowly admitted to the pontoons until the level had reached one foot. Additional inhibitor, in the amount prescribed by the inhibitor manufacturer, was added to the pontoon. The water level was raised until the entire interior of the pontoon was coated. Draining and filling was repeated; the cathodic protection systems were energized and the two week cycling schedule commenced.

After exposure for one year, the coupons were removed, steam-cleaned, washed with solvent, and electrolytically descaled in a 5 percent sulfuric acid sea water bath, containing a rust inhibitor. The coupons were wire-brushed and weighed immediately after drying.

Test Coupon Data Results

The corrosion rate for sea water only, in the submerged zone was less than that experienced in the intermittently submerged and non-submerged zones, as shown in Table 1. Although an average

reduction in corrosion rate of only 72.2 percent was achieved in the submerged zone by cathodic protection, it should be noted that the coupons were mounted parallel to the interior surface and stood out approximately three-quarters of an inch from the surface to provide corrosion rates indicative of areas shielded from the anodes such as the underside of stiffeners. The approximately 86 percent reduction in corrosion rate afforded the coupons which had received only the initial applications of floating inhibitor and no cathodic protection was surprisingly good. Upon removal, after one year of exposure, the coupons in the submerged zone had lost their shiny, oily appearance, and isolated areas were beginning to show some rusting, indicating that the coating had begun to fail.

As illustrated in Table 1, the performance of the floating inhibitors in the intermittently submerged zone was definitely superior to cathodic protection. No additional protection was discernible in this zone for those coupons receiving cathodic currents in conjunction with the inhibitor.

Table 1 also indicates that the corrosion losses were negligible for coupons located in the non-submerged zone, and initially covered with inhibitor. The coupon surfaces retained their oily appearance except in the upper portion of vertically mounted coupons, where rusting had commenced particularly with Type 1 inhibitor. The Type 2 inhibitor retained its tackiness and adhered very well to the coupon surface. The coupons that were in the pontoon without inhibitor were completely covered by rust, with rust nodules prevalent over about 25 percent of the surface area. Although pitting was more evident in the non-submerged zone than in the other areas, no pits deeper than one-sixteenth of an inch were found.

A breakdown of coupons in the submerged zone into those vertically and horizontally mounted is shown in Table 2. Corrosion losses for cathodically protected coupons in the submerged zone were virtually independent of coupon orientation. The greater losses exhibited by vertically mounted, inhibitor-protected coupons is attributed to the tendency of the inhibitor to drain off of the metal surface. Those coupons protected by both techniques exhibited negligible corrosion losses.

During the test period, the differences in corrosion rates between the pontoons with and without floating inhibitor, became visibly apparent in the non-submerged zone. In addition to rust, the presence of condensed moisture was found on the underside of the horizontal surfaces in the pontoon without inhibitor.

No special precautions had been taken to control the temperature or humidity inside the pontoons. Measurements of the temperature and relative humidity of the pontoon interiors and of exterior ambient conditions were made simultaneously, for one week, with individually recording hygro-thermographs. The difference between the pontoons shown in Figure 3 is not striking but it is believed significant since the humidity in the pontoon with floating inhibitor rarely reaches the dew point (100 percent). By contrast, the relative humidity in the pontoon without floating inhibitor is continually maintained at, or near, the dew point.

With the weekly changes in water level, the use of one rectifier, and the

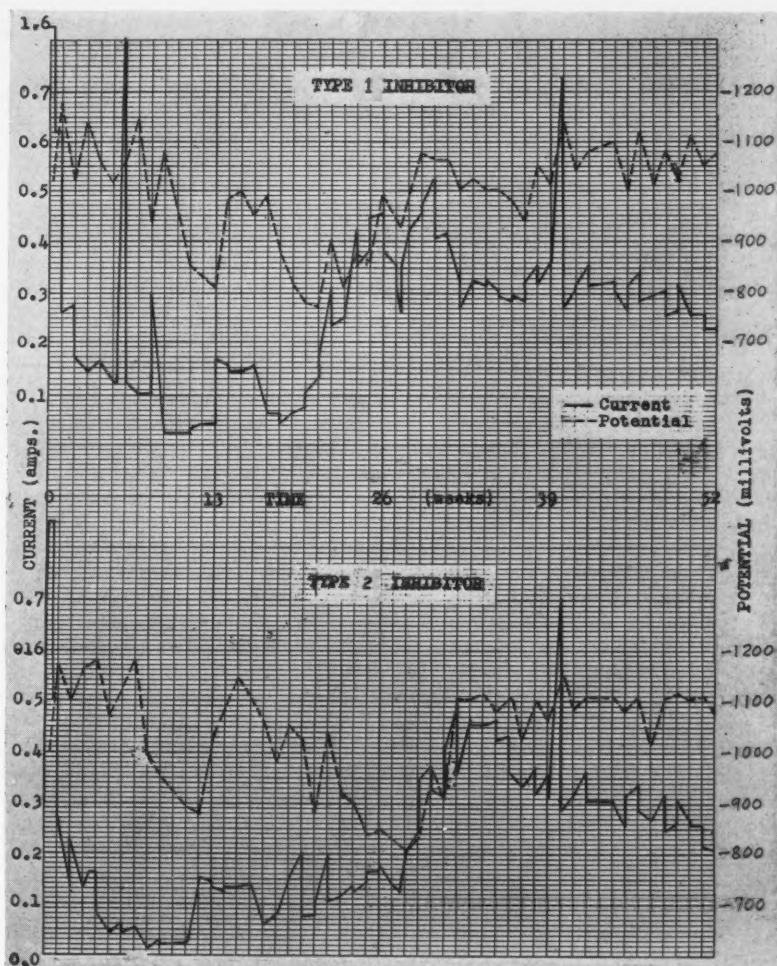


Figure 5—Potential and current data for Type 1 and Type 2 inhibitors with impressed cathodic protection current.

low driving voltage required for the three impressed current systems, it was impossible to maintain equilibrium conditions continuously at 1.0 volt. Between the ninth and eleventh weeks of operation, faulty rectifier contacts and modifications of the current control systems resulted in a low potential, indicating an inadequate supply of current. Large fluctuations in the system using cathodic protection only, as indicated in the upper portion of Figure 4, were caused by the difference in exposed metal area at the high and low water levels. The initial average current of 1.3 amp decreased to about 1.1 amp for the pontoon with cathodic protection only. Current densities of 7.3 milliamperes/sq. ft. at minimum water level and 4.8 milliamperes/sq. ft. at maximum water level were calculated at the end of the study.

There was very little difference in impressed current requirements between the pontoons containing different inhibitors as shown in Figure 5. An average initial current of 0.15 amp was impressed into the pontoon with Type 1 inhibitor, and approximately 0.10 amp was impressed into the pontoon with Type 2 inhibitor. The average final currents increased to about 0.25 amp for both of these pontoons. Current densities of 1.6 milliamperes/sq. ft. at minimum water level and 1.1 milliamperes/sq. ft. at maxi-

mum water level were calculated.

The current and potential for the pontoon equipped with the galvanic anode were more stable, as shown in Figure 4. An average current of approximately 0.10 amp was required to maintain the desired potential. The lower current requirement was attributed to either possible differences in the condition of the interior surface, or to the increasing concentration of magnesium ions in the electrolyte, as the anode was consumed. pH measurements of the residual water at the end of the study indicated a slightly higher value (more alkaline) than in the other pontoons.

The lower current requirements for the surfaces coated with the floating inhibitors are significant and emphasize the value of using a coating with cathodic protection. The reduction in current may not decrease the required number of anodes for adequate current distribution but it should materially reduce the size of anodes, the current capacity of associated components, and the current control problem because of the reduced exposed metal area.

Potential measurements taken in the pontoons containing floating inhibitor only are plotted in Figure 6. No measurements were recorded between the first and twelfth weeks. The differences between the two inhibitors' potential

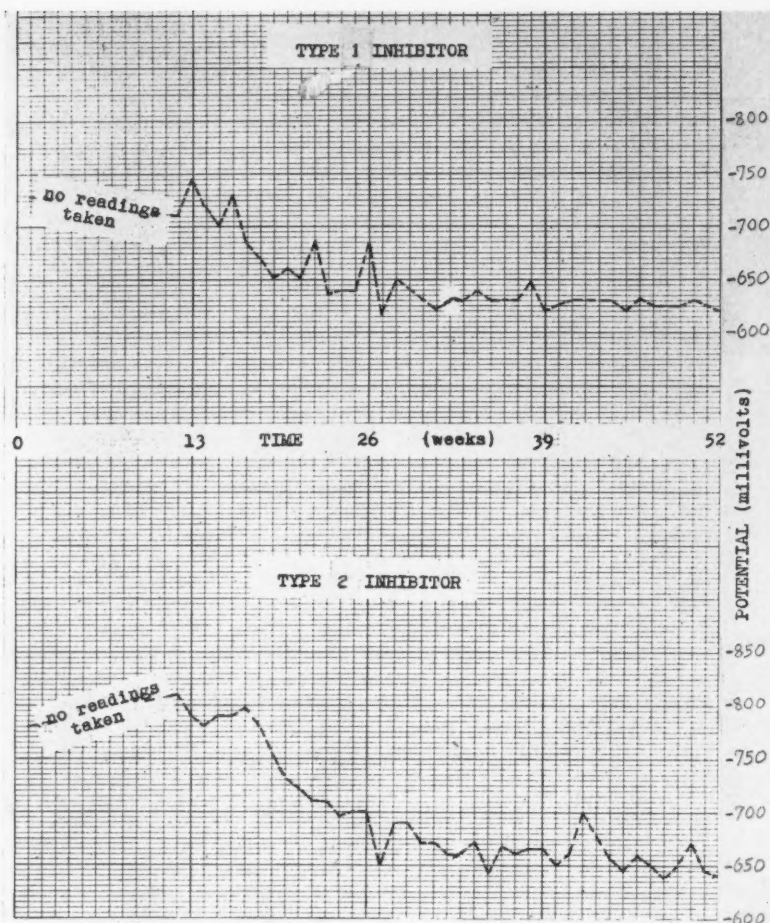


Figure 6—Potential data for Type 1 and Type 2 inhibitors without cathodic protection.

readings were attributed to special chemical additives contained in the basic material. The potentials gradually decreased as the polarizing constituents were dissipated.

On two occasions, the water level was lowered to recoat the anodes with floating inhibitor to determine the effect of the coating on the anode current-discharge efficiency. The water level was immediately raised and current values before and after recoating coincided within a period of minutes. Figure 7 illustrates the condition of the graphite anodes, in use with the floating inhibitor, at the completion of the test. The graphite anode, on the right, was wiped relatively clean to exhibit clearly areas where the greater portion of the current had been discharged. These areas were pitted to a depth of about $\frac{1}{8}$ -inch. It is not known if pitting would have become more severe, or if a greater surface area of the anode would have been utilized, if higher current densities had been used.

The magnesium anode appeared to deteriorate in a normal manner. After the study had progressed for six months, one magnesium anode served as the sole source of current for Pontoon No. 5. Evolution of a gas assumed to be hydrogen was evident by the accumulation of bubbles on the surface of the floating material directly above the anode. Because of the relatively small amount of current discharged, this phenomenon was not serious.

After six months' exposure to Type 2 inhibitor, swelling and softening of the neoprene-jacketed electric cable was observed. The softening could ultimately reduce the cable's abrasion resistance. Neoprene is susceptible to swelling in certain aromatic solvents, chlorinated hydrocarbons, and creosote.

The phenolic resin-laminated insulating material used for mounting the anodes showed a slight tendency to warp and to split after one year of exposure.

Conclusions

Under the conditions specified for simulating the operation of ballast tanks for a floating drydock, several conclusions can be made based upon the corrosion losses of preweighed, sandblasted, mild steel coupons that were exposed for one year.

1. The combined use of cathodic protection with one application of a floating-type inhibitor reduced corrosion in the permanently submerged zone to negligible amounts. In individual studies of the two methods, the corrosion rate was reduced by at least 70 percent and was somewhat dependent upon the location of the metal surface. No serious interference between the two methods was detected.

2. The corrosion rate of surfaces in the intermittently submerged zone was effectively retarded by the use of floating-type inhibitors. Cathodic protection in

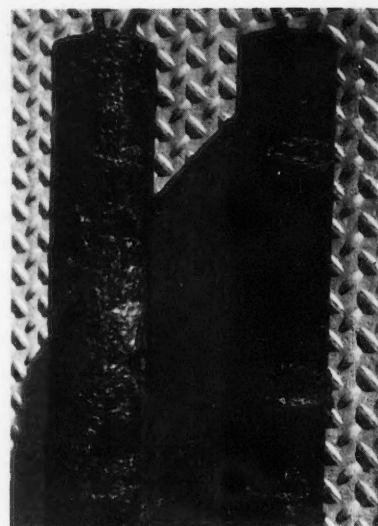


Figure 7—Graphite anodes used in conjunction with the floating inhibitors. The anode on the left is shown upon removal from the pontoon. The anode on the right was wiped clean to show deteriorated areas.

this area is effective only when the surface is submerged.

3. An initial application of floating inhibitor to metal surfaces in the non-submerged zone reduced the corrosion rate by approximately 99 percent. Protection in this area may be abetted by maintaining the relative humidity below the dew point.

4. After a one-year exposure period, the cathodic protection current required in conjunction with a floating inhibitor was one-fifth the magnitude of current required without a floating inhibitor.

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NOTE: The opinions expressed in this article are those of the author and not necessarily those of the Navy Department.

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Some Considerations in the Design and Application Of An Electrical Resistance Corrosion Meter*

By G. A. MARSH and E. SCHASCHL

Introduction

THE DESIRABILITY of using an electrical resistance method for studying corrosion has been recognized for some time. It involves measurement of the loss in thickness that occurs when a metal corrodes. When the method was first introduced it was thought in certain quarters that a conducting environment would affect the results if measurements were made while the specimen was in place.¹ This was later disproved.

Two limitations prevented exploitation of the method. For accurate work, it was necessary to control the temperature to within 0.1 degree F. In addition, it was necessary to individually compute each measurement by means of a formula or table and then convert the measurement to a thickness indication.² Temperature compensated resistance measurements were made by Stone and Webster Engineering Co. as early as 1944 but convenient instrumentation was not available at that time.³

Development of Corrosion Meter

These problems led to the development of a corrosion meter and probe method⁴ based on the measurement of electrical resistance. Dravnieks⁵ and other workers^{6,7,8,9} have recently done work in this field. The basic idea is contained in a direct reading instrument in which the loss of thickness due to corrosion of a metal probe is indicated on a meter or dial directly in penetration units (see Figures 1 and 2). A probe is connected as two arms of a Wheatstone bridge, one arm being protected by a coating of some sort, while the other arm is exposed and allowed to corrode. As long as both arms are of the same metal, the effect of temperature on resistance is cancelled out. The resistance of the exposed arm increases as corrosion proceeds.

In the present Pure Oil instrument, a small current is applied to the probe by means of a transistor oscillator. The loss of thickness as the probe corrodes appears directly on a dial in units of microinches (millionths of an inch.) The null amplifier also is transistorized; the entire unit is portable and is powered by penlight batteries. Calibration is essentially the same as described in a previous paper.⁴

Figure 3 depicts probes which are made in considerable quantity at these laboratories. The probes are used for corrosion testing in many of the company's operations. Type A is mounted on a rubber stopper and can be inserted



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into any environment where there is little or no pressure and where temperatures are under about 250 F. Type B is a plug-mounted probe. Type C, retractable, can be installed and removed from a corrosive environment by a suitable valve and piping arrangement without interrupting the operation of the unit. Type D is a high pressure type which will withstand pressures up to 15,000 psi. In these special probes, the corroding element can be replaced after use by breaking away the coating and re-installing the corroding strip.

The laboratory Type A probes are usually made in one mil thickness (1 mil = 0.001 inch), while the more rugged types measure 10 mils and can be made thicker if long term use is desired. The shields around the long term probes provide protection against mechanical damage during installation and also provide some measure of protection against debris while in service.

Figure 4 shows one operation of probe construction in the machine shop of these laboratories. The probes usually are made in batches of 200 at a time.

Most of the testing work has been done with SAE 1010 cold rolled steel. For a comparative test, it is not necessary to use probes of composition identical to that of a field structure, although the composition should be reasonably close. The probes can be made of any metal that is available in thin foil or

Abstract

Considerations in design of a direct-reading corrosion meter using temperature-compensated electrical resistance specimens or probes are described. A number of laboratory and field applications are discussed, with special emphasis on applications in the petroleum industry.

One of the principal advantages of the probe method is that it enables the operator to make measurements while corrosion is proceeding without interrupting the test and without making separate temperature corrections or calculations. The method cannot be used to measure pitting.

2.4.2

wire form. For low temperature use the probes are assembled by soldering, but for high temperature use they are assembled by silver soldering or spot welding. The most satisfactory coating for temperatures up to 300 F is an epoxy resin. At temperatures up to 700 F, success has been had with probes that have been glass coated by an A. O. Smith process.

Probe element thickness, rather than length, is the factor which determines meter sensitivity. For a given corrosion loss, the ratio of corrosion loss to original thickness is greater with thin elements than it is with thick elements. The meter measures this ratio—hence meter sensitivity increases with decreasing thickness of probe elements. The other dimensions of the probe remain fixed as corrosion proceeds; consequently the length and width of the probe elements do not affect sensitivity. However, the length and width are taken into account in making the probes, in that these dimensions determine the total probe resistance for a given thickness.

For convenience in application, a probe length of 3 inches is commonly used. One mil steel probes of this length have a resistance of about 0.1 ohm.

The meter is designed to operate over a range of probe resistances from approximately 0.005 ohm to 0.2 ohm. To accommodate probes of thick metal (e.g., 40 mil), it is necessary only to adjust the probe length so that the resistance will fall into the useable range. Similarly, foils of less than 1 mil thickness can be used by adjusting the probe resistance—in this case by increasing the width of the probe element while keeping the length very short.

Probe life decreases as probe sensitivity increases. Table 1 shows the effect of probe thickness on the useful life of the probe. As would be expected, the 1 mil probes have a brief probe life. At 0.010 ipy corrosion rate, for example, the probe life is approximately 100 hours. It is apparent that in using probes, one must balance sensitivity with length of the test.

The maximum sensitivity with a 1 mil

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Figure 1—Portable corrosion meter.

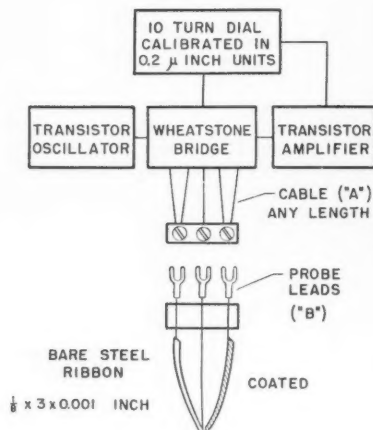


Figure 2—Diagram of corrosion meter.

probe is a fraction of a microinch. In a practical sense, however, a minimum of several microinches loss of thickness is required before an accurate corrosion-time curve can be established. The thick probes are less sensitive but yield data that are just as accurate when the data are taken over a correspondingly longer period of time. The use of flat ribbon rather than wire seems to be desirable for short term use because, to get adequate sensitivity, fine wires must be used. This renders the wire sensitive to uneven attack. For long term use heavy wires are satisfactory.

The effect of lead resistance enters into the meter in two places: first, in the leads from the instrument to the probe, and secondly in the leads which are integrally connected to the probe itself. Lead resistance in the first case ("A" in Figure 2) is eliminated by running separate wires for current and potential leads—an application of the Kelvin bridge principle. Lead resistance in the second case (i.e., on the probe itself, "B" in Figure 2) is significant only when the leads are more than 6

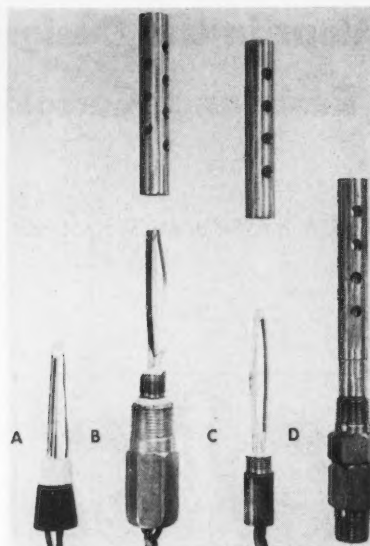


Figure 3—Typical corrosion test probes.



Figure 4—View showing probes being assembled in machine shop.

TABLE 1—Relationship Between Probe Thickness and Probe Life

Thickness (Mils)	Probe Life (0.01 ipy Rate)
1.....	100 Hours
10.....	30 Days
40.....	6 Months

inches long. Separate current and potential leads must be used here too if these leads are longer than 3 feet. Long leads on the probe result in a predictable reduction of sensitivity but have no other deleterious effect.

Probes of the flat ribbon type are not sensitive to pitting. For example, a 0.040-inch hole drilled through a 1 mil probe element will cause a meter reading of only 5 microinches. The reason for this is the fact that the resistance of the corroding element depends on average cross-sectional area, which is only slightly affected by small holes.^{2,4} An engineer using probes for corrosion testing must therefore exercise some judgment if the probes are installed in an unusual pitting environment. Visual inspection of the probe upon removal will indicate whether pitting is severe enough to invalidate the corrosion meter data.

As a general rule, the higher the corrosion rate the more reproducible are the

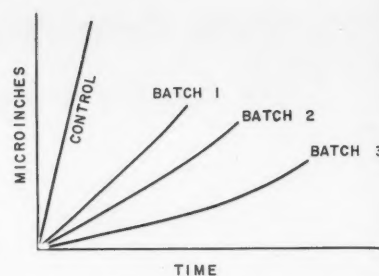


Figure 5—Inhibitor performance test data.

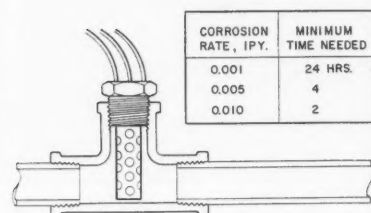


Figure 6—Probe installation in oil well flow line.

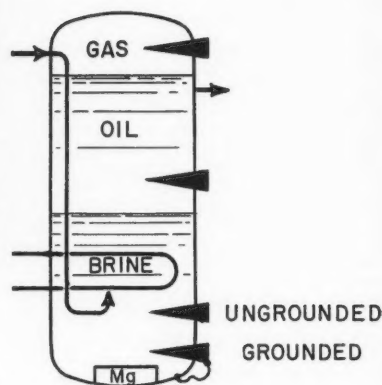


Figure 7—Probe testing in large oil field emulsion treating tower.

readings. With mass produced unannealed probes, the reproducibility of corrosion readings from one probe to another is within 5 percent under most conditions. The only problem with reproducibility found thus far is in the testing of low concentrations of corrosion inhibitors. Here the corrosion rate may remain low for a long period of time in some tests but may increase after a comparatively short time in other tests. Testing of this type is most effectively dealt with by statistical methods.

Correlations between probe data and equipment service data have been attempted in only a few cases. In such instances good agreement was obtained. However, because of the small size of the test specimens, in a general case there may be only a rough agreement with the actual plant corrosion rate of a large structure having the same environment. For this reason probe tests are designed wherever possible as comparative tests (i.e., the corrosive environment is changed from one test to another so that a comparison of the different conditions can be measured by the probes). No attempt should be made to

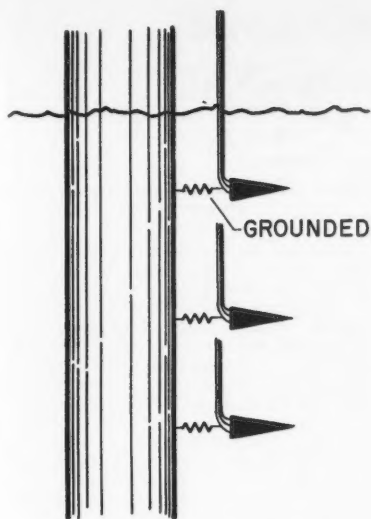


Figure 8—Testing of cathodic protection of marine structures.

extrapolate the results of a probe test of a few hours or a few days duration.

Applications of the Corrosion Meter

One of the most important applications of the corrosion meter is in the rotating bottle corrosion test. The apparatus has been described in connection with development of tanker rust inhibitors.¹⁰ This apparatus has proved to be very useful in the study of corrosion under conditions where two phases are involved.

Inhibitor testing leads to another possible application of the corrosion meter, as shown in Figure 5. It has been found that inhibitor batches as received from the manufacturer may vary in inhibiting ability. A simple performance test could be carried out in the laboratory to ensure that the dollars spent on inhibitor are actually being put to work in saving metal loss. The performance test could be set up in such a way that the laboratory test would in some measure duplicate field or plant conditions.^{11,12}

Figure 6 shows an application of the corrosion meter in a study of oil well corrosion. Here a probe is inserted in a tee in an oil well flow line. Usually a few readings are sufficient to establish the rate at which the probe is corroding. The higher the corrosion rate, the less time is required to establish the rate. Perhaps 48 hours would be required to establish a rate of 1 mil per year (mpy) accurately, while only 5 hours would be required to establish a rate of 10 mpy. However, even in the case of a low corrosion rate of 1 mpy, it takes only 2 hours to tell that the rate is less than 2 mpy. So a field engineer making a corrosion survey of a field need not establish the corrosion rate exactly. He may take readings only often enough to make sure that the corrosion rate is below a minimum value.

Figure 7 shows an application in checking corrosion in an oil field emulsion treater. Probes were used to determine the corrosion rate in the gas zone, oil zone, and brine zone of the treating tower. By using grounded as well as ungrounded probes in the brine zone, the effectiveness of cathodic protection was readily determined. The effectiveness of different inhibitors and remedial meas-

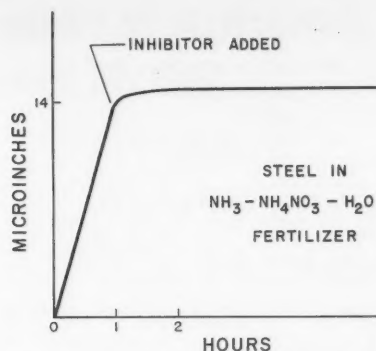


Figure 9—Effect on inhibitor on corrosion of steel in nitrogen fertilizer solution.

ures could be observed in a matter of days rather than months as was previously done using test panels.

Figure 8 shows an application in testing cathodic protection of marine structures such as off-shore platforms. Probes can be installed at various depths. Also, small shunt resistors can be installed between the probes and the structure in order to provide a measurement of the actual current density on the probes. This gives a method for measuring the corrosion rate as related to cathodic protection current density on the actual structure. If low readings are obtained on sensitive probes, a corrosion engineer can be certain that the marine structure is adequately protected. The effect of insulating vertical structures from horizontal ones in marine applications can be demonstrated also by using probes to make the corrosion measurements. A similar setup can be used in connection with cathodic protection of buried pipe.

The probe technique can be used in a laboratory test setup for determining the effect of cathodic protection current density on corrosion rate.¹³ The apparatus is arranged so that different cathodic protection current densities can be applied to the probes, thus permitting simultaneous measurement of corrosion rate and current density. Also, differential aeration can be studied conveniently. Probes either can be connected together in a differential aeration cell or they can be left unconnected to provide the freely corroding rate at each point. Such a test has given interesting theoretical information. It was found, for example, that differential aeration cells which operate vigorously in a homogenous liquid medium do not operate in the presence of a porous medium such as sand.

Probe measurements can be used to determine cathodic protection minimum current density.¹⁴ When corrosion rate is plotted against current density, a sharp break occurs at the point of protection. This seems to be easier to obtain than the frequently-used plot of pipe-to-soil potential vs current density.

Figure 9 shows an application in a petro-chemical field. There is a severe corrosion problem when steel is exposed to nitrogen fertilizer solution made up of $\text{NH}_3\text{-NH}_4\text{NO}_3\text{-H}_2\text{O}$. Corrosion rates of 200 mils per year are observed when steel is immersed in uninhibited solutions. The figure illustrates the dramatic effect when a corrosion inhibitor is added to such solutions.

Figure 10 shows a laboratory setup in which a high pressure cycling system was used to determine corrosion in the liquid, vapor, and condensing zones of

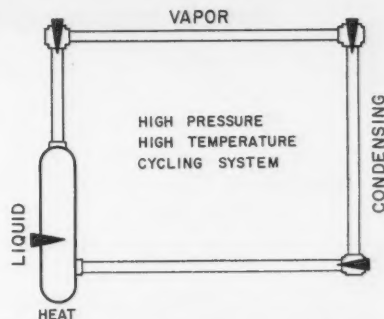


Figure 10—High pressure laboratory system for corrosion study.

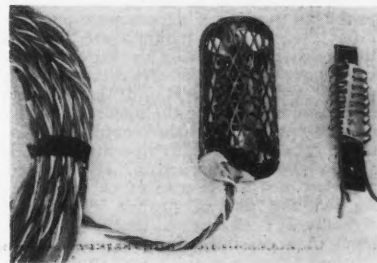


Figure 11—Long term spiral probes for tanker use.

a stream containing phenol and oil. Corrosive agents were added to the cycling material to determine possible constituents that could cause corrosion in a large scale refinery unit. Test runs of only one day's duration were required to establish the corrosion rates with the needed accuracy.

In a previous paper,¹⁴ tanker corrosion was studied with short term, sensitive probes. Subsequently, long term probes have been used to test oil soluble corrosion inhibitor efficiency. Figure 11 shows the spiral construction and also a finished, shielded probe.

Figure 12 shows data obtained in gasoline storage and blending tanks. Corrosion rates in tanks containing the components which were blended together showed low rates—from 0 to 3 mils per year. In the blending tank, probes showed a consistently high rate of 12 to 16 mils per year. This information was in agreement with the observations of refinery operators, who noticed that there seemed to be more corrosion in the blending tank than in the tanks containing the components. The high corrosion rate is believed to be caused by the presence of water containing dissolved solids and oxygen, and by vigorous agitation.

Based on data available at this time, it appears that the conductivity of the water phase present in gasoline determines the corrosion process that will occur. At a water conductivity of less than about 0.1 reciprocal ohm-meter, the corrosion rate is a function mainly of the conductivity of the water phase. Dissolved oxygen and agitation have little effect in this range. Above this critical conductivity, corrosion rate depends on dissolved oxygen concentration and agitation. Thus, sea water contamination of gasoline has a drastic effect on the corrosion of steel in gasoline, while fresh water contamination has little or no effect. The presence of rust on steel may

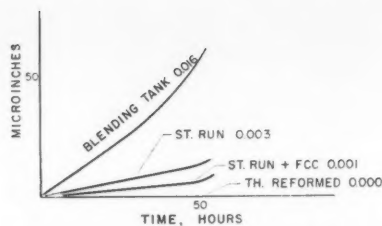


Figure 12—Data obtained in gasoline blending and component tanks.

provide local conductivity even though the bulk environment has high resistance.

Figure 13 gives some of the factors involved in the use of probes in refinery process streams. Application of the probe method here depends on accessibility, safety, and temperature fluctuations of the stream. This latter factor is of importance in streams carrying vapor and liquid. Rapid temperature fluctuations decrease the accuracy of the instrument because the coated part of the probe changes temperature more slowly than the bare part. The present authors⁴ and Troscinski et al.¹⁵ have described the use of probes in refinery streams. It is envisioned that if the problems of accessibility and safety can be worked out, one could have a multi-point corrosion recorder located in the control room of a refinery. The refinery operator could check on the use of caustic, ammonia, or corrosion inhibitors, merely by inspecting the daily record.

Figure 14 shows an application of the probe technique to the study of engine corrosion. Measurements can be made while the engine is running. This leads to a practical way of developing fuels and lubricants from a corrosion standpoint. The chemical effect of lubricants

REFINERY PROCESS STREAMS

APPLICATION DEPENDS ON:

ACCESSIBILITY
SAFETY
TEMPERATURE FLUCTUATIONS
OF STREAMS



Figure 13—Application of probe method to refinery process streams.

on bearings can be studied by making probes out of bearing metal. Cooling system corrosion can be studied semi-quantitatively by galvanically coupling probes of dissimilar metals while they are exposed to the coolant.

Summary

As with any test involving a small specimen, the probe method will not necessarily indicate the exact corrosion rate of large structures. For this reason, the probes are best used for obtaining relative rather than absolute corrosion rates. Probe experiments should be designed as comparative tests. In such tests the probes are sensitive to small variations in corrosivity and give better reproducibility than conventional weight loss tests.

Pitting cannot be measured by the probe method, as the probes are not sensitive to pitting.

The main advantage in the probe method is that measurements can be made while corrosion is proceeding without interrupting the test and without making separate temperature corrections or calculations of any kind. Comparative

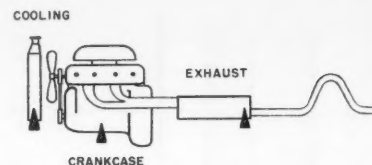


Figure 14—Application of probe method to engine corrosion testing.

results can be obtained in tests of very short duration. Readings can be made quickly, as often as desired, or they can be automatically and continuously recorded. Small changes in corrosive environment can be detected. Many tests can be carried out at the same time with one piece of apparatus. The results are quantitative and reasonably reproducible.

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Any discussions of this article not published above will appear in the June, 1958 issue

Stress Corrosion of Austenitic Stainless Steel In Geothermal Steam*

By T. MARSHALL

Introduction

NUMEROUS INVESTIGATORS¹⁻¹¹ have reported stress corrosion of austenitic stainless steels in hot chloride solutions. Such corrosion usually occurs in strong solutions at temperatures exceeding 100 C and under conditions where the presence of dissolved oxygen is not deliberately avoided. In discussing plant experience Collins¹² suggests 50 ppm of chlorides and 50 C as the minimum concentration/temperature requirements for stress corrosion. Other authors reporting on stress corrosion of austenitic stainless steels in chloride-contaminated steam are Davis¹⁰ and Edeleanu.⁵

Naturally-occurring steam (the so-called geothermal steam) is currently being developed at Wairakei, New Zealand, for the planned production of electric power in steam turbo-alternators. The Wairakei district, situated in volcanic country, is characterized by thermal activity in the form of hot springs, natural steam vents, geysers, fumaroles etc. The geothermal steam is obtained by drilling boreholes (up to 8-inches in diameter, 3000 feet deep) in the thermally-active areas. Wet steam discharged from the bores (at rates up to 600,000 lb/hr) is highly contaminated with chlorides, hydrogen sulfide, carbon dioxide etc. Hence, when corrosion investigations¹³ in this geothermal steam were initiated in 1952, stress-corrosion cracking of austenitic stainless steel was expected.

Test results proved indeterminate, however, in that only two minute stress-corrosion cracks were observed on the numerous stressed specimens of various austenitic stainless steels exposed. The fact that these two cases occurred only in geothermal steam which had been deliberately contaminated with oxygen by air injection, suggested¹³ that the presence of oxygen is essential to the stress-corrosion mechanism. The steam, as derived from the geothermal bores, cannot contain significant amounts of oxygen owing to reaction with hydrogen sulfides present. Ellis¹⁴ has estimated that the equilibrium oxygen concentration in the steam is infinitesimally small (much less than 0.002 ppm).

In view of the indeterminate results of the previous tests, further stress-corrosion investigations were conducted in 1955 to study more closely the significance of oxygen contamination on stress corrosion of austenitic stainless steels in steam. These latter investigations are the subject of this paper.

Hoar and Hines¹⁵ have independently postulated, on theoretical grounds, that cathodic inhibition by the complete exclusion of oxygen probably would pre-

About
the
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vent transcrystalline stress corrosion of austenitic stainless steels. The present work thus is of interest in providing an experimental test of Hoar and Hines' theoretical postulate.

The work is of considerable practical significance in connection with the utilization of geothermal steam, since austenitic stainless steels have shown a marked advantage over the martensitic/ferritic grades normally employed for turbine blading. The first-mentioned steels exhibit higher resistance to surface corrosion and essential immunity to sulfide stress corrosion in the steam.¹³

Steam Conditions

Steam used in the investigations was separated, nominally at 85 psig, from the mixed steam/water discharge of No. 9 geothermal bore at Wairakei, New Zealand. At 85 psig the bore discharge consists of 72 weight percent of water and 28 weight percent of steam, with compositions as given in Table 1. Hence the separated steam used in the tests consisted of vapor with composition as listed in the steam-phase column of Table 1, contaminated with approximately 0.2 weight percent of residual water droplets of composition as in the water-phase column of Table 1. The droplets were carried over from the commercial-type cyclone separator. Thus, while the chloride content of the separated steam averaged 3 ppm, the chloride concentration in the entrained water droplets would be 1500 ppm.

It will be noted that earlier tests¹³ in separated steam under similar conditions produced no stress corrosion of austenitic stainless steels. The two cases of stress corrosion previously mentioned,

Abstract

Stress corrosion tests on austenitic stainless steels were conducted in geothermal steam contaminated with chlorides, hydrogen sulfide, carbon dioxide etc., under the following steam conditions: (1) Air-free steam superheated at 150 C, and (2) Steam superheated and aerated at 150 C.

Stress-corrosion cracking occurred readily in the aerated, superheated steam, but did not occur at all in the air-free, superheated steam. These test results provide experimental confirmation of Hoar and Hines' theory that the cathodic depolarizing action of oxygen is essential to the stress-corrosion mechanism. For comparison purposes corrosion-rate data, and stress-corrosion data on other alloys in the steam are given. Factors controlling the stress corrosion of austenitic stainless steel in geothermal steam are discussed. 4.2.3

occurred only when such steam was deliberately aerated.

If geothermal steam, separated as above, is partly condensed to a few percent wetness, condensation on the entrained water droplets will rapidly reduce the concentration of chlorides and other solid impurities in those droplets. Again, the previous tests showed no stress corrosion of austenitic stainless steels in partly condensed steam of this type.

On the other hand, if separated steam is subsequently superheated to a moderate degree, evaporation from the residual water droplets concentrates the chlorides and other solid impurities in those droplets. These effects have been observed in the accumulation of sticky salt/silica deposits in superheated steam pipes. Ultimately, a sufficiently high degree of superheat will completely evaporate the residual impure water droplets, leaving dry solid impurities in the steam.

Edeleanu's¹⁶ views on the relationship between steam environment and the stress corrosion of austenitic stainless

TABLE 1—Approximate Composition of Discharge Fluid, Bore No. 9

CONSTITUENT	Concentration, Parts per Million By Weight	
	In Steam Phase	In Water Phase
Carbon dioxide.....	5,400	5
Hydrogen sulfide.....	140	0.5
Ammonia.....	15	3
Boric acid.....	0.6	160
Fluoride (F ⁻).....	0.03	6
Chloride (Cl ⁻).....	Nil	1,500
Sodium.....	Nil	900
Potassium.....	Nil	60
Silica.....	Nil	300

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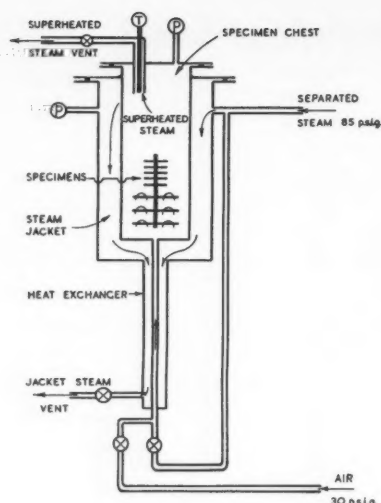


Figure 1—Diagrammatic arrangement of test equipment. Code to circled letters is as follows: P—pressure gauge; T—thermometer; X—valve.

steels are of interest. He suggests that the environment will be most aggressive when the steam is moderately superheated so as to concentrate, but not to completely dry, the chloride solution droplets in the steam. For this reason, and since previous tests¹⁰ in air-free steam with a superheat of 1.5 C did not produce stress-corrosion cracking, the present tests were conducted in aerated and air-free geothermal steams at a nominal superheat of 25 C.

Test Methods

Superheating was effected by expanding the separated steam from 85 psig down to 0-25 psig and into a tubular heat exchanger jacketed with the higher-pressure steam. The superheated steam then flowed continuously through a specimen chest which was also jacketed with the higher-pressure steam. For tests in aerated superheated steam, air from an auxiliary steam-driven air compressor was pumped into the head of the heat exchanger, the relative proportions of steam and air in the chest being assessed by observing the drop in total pressure of the system when the air supply was shut off. Arrangement of the test equipment is illustrated diagrammatically in Figure 1.

For stress-corrosion tests, constant-deformation specimens of the U-bend type,² fabricated from commercial austenitic stainless steel of thickness up to 80 mils, were stressed appreciably into the plastic range and mounted on exposure racks with due precautions to avoid any contact with dissimilar alloys. Analyses and mechanical properties of alloys used are listed in Table 2.

The following media were chosen for the exposure tests:

1. Air-free superheated geothermal steam nominally at 20 psig and 150 C, equivalent to a nominal superheat of 25 C. Except during a few shutdowns for repairs and examinations, steam conditions were maintained at 20 ± 5 psig and 150 ± 5 C during the 101-day

test period in this medium. Superheat was thus maintained at 25 ± 5 C, and aeration in the steam chest occurred only during the few short shutdown periods.

2. Aerated, superheated geothermal steam nominally at 40 psia total pressure (partial pressure of steam 35 psi, partial pressure of air 5 psi) and at 150 C. Except during a few short shutdown periods, steam conditions were maintained at total pressure 40 ± 5 psia, air partial pressure 5 ± 2 psi, temperature 150 ± 5 C, equivalent to a nominal superheat of 25 ± 7 C during the 108-day test period in this medium.

After exposure to the above media, stress-corrosion specimens were examined visually for cracks, further plastic deformation of the U-bends and re-examination being applied if no cracks were initially visible. Finally, metallographic sectioning of a number of cracked specimens revealed the characteristic modes of the stress-corrosion attack. Surface-corrosion-rate determinations followed the ASTM recommended procedures.¹⁷

Test Results

Results of the tests are listed in Table 3, stress-corrosion data being designated by the symbols O, indicating no cracking of one U-bend specimen during exposure, and X, indicating cracking or fracture of one specimen during exposure to the appropriate medium. Average corrosion rates are reported to one significant figure, and to the number of decimal places appropriate to the accuracy of the method of determination. The observed dominant corrosion characteristics are classified according to Champions' shorthand system.¹⁸

In a further confirmatory series of

TABLE 2—Analyses and Tensile Strengths of Alloys Tested

ALLOY	ANALYSIS, WEIGHT PERCENT														Tensile Strength, psi	Remarks
	C	Si	S	P	Mn	Ni	Cr	Mo	Cu	Ti	Cb	Fe	Al	Zn		
18/8 Cr Ni Stainless Steel A.....	0.10	0.5			0.65	8.9	18.5			<0.05		Rem ¹			94,000	0.2% Proof Stress—44,000 psi.
18/8 Cr Ni Stainless Steel B.....		0.6			0.7	7.9	17.8	0.2		<0.02		Rem			99,000	0.2% Proof Stress—47,000 psi.
18/8/3 Cr Ni Mo Stainless Steel A.....	0.05	0.3			0.3	7.9	17.6	3.2	0.3	<0.02		Rem			100,000	0.2% Proof Stress—45,000 psi.
18/8/3 Cr Ni Mo Stainless Steel B.....	0.06	0.3			0.4	8.4	18.4	3.1		0.4		Rem			90,000	0.5% Proof Stress—40,000 psi.
18/10/1 Cr Ni Cb Stainless Steel.....	0.11	0.5			0.4	9.5	17.8				1.2	Rem			91,000	0.5% Proof Stress—39,000 psi.
18/12/1 Cr Ni Cb Stainless Steel.....	0.12	0.8			1.4	12.1	18.5				1.3	Rem			91,000	0.5% Proof Stress—39,000 psi.
18/12/2 Cr Ni Mo Stainless Steel.....	0.10	1.0			0.8	11.5	17.1	2.3				Rem			85,000	0.2% Proof Stress—39,000 psi.
13Cr Stainless Steel.....	0.07	0.3			0.2	<0.2	13.3	<0.1				Rem			59,000 67,000 140,000	Annealed, Hardness Rockwell B60. Hardened, tempered 750 C, Hardness Rockwell B80 Hardened, tempered 450 C, Hardness Rockwell C30
13/3 Cr Mo Stainless Steel ²	0.12	0.6			0.5		12.5	3.1				Rem				Hardened, tempered 750 C, Hardness Rockwell B98 Hardened, tempered 450 C, Hardness Rockwell C30
Mild Steel.....	0.24	0.07	0.04	0.01	0.3				0.2			Rem			67,000	
Titanium ³															92,000	
Aluminum.....		0.2			1.4				0.04			0.5	Rem		16,000	
Monel.....					1.1	Rem.			29.5			2.1			81,000	
Inconel.....		0.4			0.2	77.9	13.0			0.25		Rem			90,000	
60/40 Brass.....									60.8					Rem	58,000	

¹ Rem = Remainder.

² Hot-rolled strip from an experimental melt of stainless steel.

³ Commercially pure sheet.

tests in air-free geothermal steam with superheat varying from 0 C to a maximum of 31 C, no austenitic stainless steels exhibited stress-corrosion cracking.

The stress-corrosion of hardened 13 Cr and 13/3 Cr Mo stainless steels experienced in the tests took the characteristic form in each case of a single fracture passing completely through the stressed limb of the U-bend. This cracking is presumed to be due to sulfide stress corrosion, to which these non-austenitic alloys are known to be susceptible.^{10, 19}

In the austenitic specimens, stress corrosion occurred as fine, multiple, tensile-surface cracks, with very little 'yawning'. These cracks required close examination under a powerful binocular microscope for visual detection. In no case did they pass completely through the stressed limbs of the U-bend specimens. Metallographic sectioning showed frequent multiple branching of the cracks and a predominantly transcrystalline habit, both of which characteristics are typical of chloride stress corrosion in austenitic stainless steels.^{9, 10}

Discussions

The present and previous investigations show clearly that austenitic stainless steels, even under severe applied stresses, resist stress-corrosion cracking in air-free geothermal steam heavily contaminated with chlorides and hydrogen sulfide. However, stress corrosion occurs readily when the steam is moderately superheated and simultaneously contaminated with oxygen by aeration.

These observations are interpreted as follows, the interpretations being based on the present work and on published

researches by other investigators. For stress-corrosion cracking of austenitic stainless steels by geothermal steam, five conditions must be satisfied simultaneously:

1. The steel, as established by numerous investigators, must be in a state of tensile stress. Cracking can occur under very low stresses.¹⁰

2. On the basis of the electrochemical theory of corrosion and the electrochemical nature of the stress-corrosion phenomenon,¹⁰ it is assumed that a water phase must be present in the steam. Steam separated from geothermal steam/water mixtures always contains water due to spray carryover from separators, unless the steam is subsequently dried by a high degree of superheating.

3. An elevated temperature is necessary. The minimum temperature requirement of 50 C quoted by Collins,¹² is automatically provided by the steam at pressures in excess of 2 psia.

4. The water phase of the steam must contain chlorides to meet the requirements for typical transcrystalline stress corrosion as established by other investigators.^{1, 12} In geothermal steam practice the chlorides are supplied by carryover of chloride-water droplets from steam separators, the amount of carryover being controlled by separator efficiency. To initiate stress corrosion, the chloride concentration in the water phase presumably must exceed a certain minimum value which has not yet been established, but which, according to Collins,¹² may be as low as 50 ppm, and from previous tests,¹² appears to be of the order 1500 ppm under geothermal steam conditions. The required minimum chloride concen-

tration probably would be influenced by temperature, pH, and other variables.

In geothermal steam practice the water-phase chloride concentration is controlled by thermal treatment of the steam subsequent to separation; partial condensation of the steam, as in turbines, rapidly reduces the concentration of chlorides in the water phase. The present tests indicate that moderate superheating, by its action in concentrating the water-phase chlorides, facilitates stress corrosion.

5. Oxygen must be present in the steam, as established by the present investigation. Oxygen introduced by aeration is distributed between the vapor and water phases in accordance with its equilibrium distribution co-efficient at the ruling temperature, and is not rapidly eliminated by the slow reaction with H₂S in the steam. Thus dissolved oxygen supplied to the water phase in the steam would fulfil Hoar and Hines'¹³ postulated requirement for the cathodic stimulation of stress corrosion. It is pertinent to inquire whether, at temperatures much higher than those used in these tests, other cathodic reactions could stimulate stress corrosion. In geothermal media this does not appear to be the case, since tests in geothermal water at 240 C, contaminated with H₂S, chlorides (1500 ppm) etc., have produced no stress-corrosion cracking of austenitic stainless steels. Furthermore the natural occurrence of oxidizing agents in the strongly reducing geothermal fluids is highly unlikely.

Although the above conditions for stress corrosion apply strictly to only the geothermal steam used in these tests, it is possible in principle that they also

TABLE 3—Corrosion Test Results

ALLOY	TESTS IN AIR-FREE SUPERHEATED STEAM			TESTS IN AERATED SUPERHEATED STEAM		
	Average Corrosion Rates, ipy	Corrosion Classification ¹	Stress Corrosion Test Results	Average Corrosion Rates, ipy	Corrosion Classification ¹	Stress Corrosion Test Results
18/8 Cr Ni Stainless Steel A.....	.0000	Nil	000,000	.0000	M31 K3	XXX,XXX
18/8 Cr Ni Stainless Steel B.....	—	—	000,000	—	—	XXX,XXX
18/8/3 Cr Ni Mo Stainless Steel A...	.0000	Nil	000,000	.0000	M11	XXX,XXX
18/8/3 Cr Ni Mo Stainless Steel B...	—	—	000,0	—	—	—
18/10/1 Cr Ni Cb Stainless Steel.....	—	—	000	—	—	—
18/12/1 Cr Ni Cb Stainless Steel.....	—	—	0	—	—	—
18/12/2 Cr Ni Mo Stainless Steel.....	.0000	Nil	000,0	.0000	M21 K3	XXX,X
13 Cr Stainless Steel, Annealed.....	.0000	M51	000	.0002	M61	000
13 Cr Stainless Steel, hardened, tempered 750 C.....	—	—	000	—	—	000
13 Cr Stainless Steel, hardened, tempered 450 C.....	—	—	000,000	—	—	XXX,XXX
13/3 Cr Mo Stainless Steel, hardened, tempered 750 C.....	—	—	00	—	—	00
13/3 Cr Mo Stainless Steel, hardened, tempered 450 C.....	—	—	0XX,XXX	—	—	X
Mild Steel.....	.0005	Gu2	00	.002	Gu3	00
Titanium.....	.0000	Nil	00	.0000	Nil	00
Aluminum.....	.0003	M23	00	.0008	M42	00
Monel.....	.0006	Gu2	00	.001	Gu2	00
Inconel.....	.0000	Nil	00	.0001	W32 M61	00
90/40 Brass.....	.001	Gu2,Dz5	00	.001	Gu2,Dz5	Dz5

(1) Corrosion classification according to Champion's shorthand system.¹⁸

M indicates medium pits with average depth/width ratios about 1.

Gu indicates uneven, general, surface attack.

Dz indicates dezincification.

W indicates wide pits with average depth/width ratios about 1/4.

K indicates cracking due in part to corrosion (e.g., cracking round stamped index numbers).

Nil indicates no detectable attack.

0 indicates no cracking of one U-bend specimen during exposure.

X indicates cracking or fracture of one specimen.

The numerals refer to a standard scale¹⁸ for frequency and/or severity of the above types of attack; the larger the numeral, the more severe or more frequent the attack.

may apply to other steam systems, such as boiler-steam plants. Independent investigations by Williams and Eckel²⁰ suggest that this is the case. However, further confirmation would be desirable for systems where the factors of acidity, temperature, composition vary markedly from the present test conditions.

It must be emphasized that all five of the above conditions must be satisfied simultaneously to permit stress corrosion in geothermal steam; failure to satisfy any one condition will prevent attack. Thus conditions in a turbine operating on geothermal steam would not be conducive to stress-corrosion cracking of austenitic stainless-steel components, since in stages operating above atmospheric pressure accidental aeration of the steam could not readily occur. In stages operating below atmospheric pressure, aeration by air leaks could accidentally occur, but temperatures would be low and water-phase chloride concentrations in the partly condensed wet steam would in practice be less than 50 ppm. As a result stress-corrosion cracking would not be expected. Complete sealing of low-pressure casings to prevent air ingress would, of course, be an effective deterrent to stress corrosion in low-pressure stages. In view of the present elucidation of factors controlling their stress-corrosion behavior, and in

view of their resistance to normal surface corrosion,²¹ the austenitic stainless steels show great promise as materials for turbine-blading service in geothermal steam. Their promising behavior must be ascribed largely to the presence of H₂S and reducing conditions in the steam.

From the theoretical viewpoint the present work is of particular interest in providing experimental confirmation of Hoar and Hines¹³ theoretical deduction that the cathodic stimulating action of oxygen is essential to the mechanism of transcrystalline stress corrosion in austenitic stainless steels.

Acknowledgments

The author wishes to acknowledge the very valuable advice of Dr. C. Edeleanu, of Firth Brown Research Laboratories, in planning these tests. Thanks go to Dr. Weir of Glasgow University, Mr. Bradley of Admiralty Metallurgical Laboratory, and the English Electric Company for assistance in discussions and provision of alloys for testing. The valuable services of R. L. Ledger and A. Tombs of Dominion Laboratory in design, fabrication, and operation of test equipment are acknowledged. Thanks are offered to the Director, Dominion Laboratory for permission to publish this paper.

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Any discussions of this article not published above
will appear in the June, 1958 issue

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Discussions on technical articles published in *Corrosion* will be accepted for review without invitation. Discussions must be constructive, accompanied by full substantiation of fact in the form of tables, graphs or other representative data and be submitted in three typewritten copies.

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TECHNICAL COMMITTEE ACTIVITIES

AC Corrosion of Aluminum Cable Is Reported

Probable Mechanism Of Reaction in Saline Water Postulated

Corrosion of aluminum cable submerged in water when subjected to alternating current has been experienced in one instance and has been confirmed experimentally in the laboratory. This news developed at a meeting of T-4B-1C, A work group of Task Group T-4B-1 on Lead and Other Metallic Sheaths at St. Louis in March 1957.

A section of eight 350 MCM aluminum mains was pulled between a manhole and service box in June, energized at the manhole with 110 volts and ends at the service box taped with rubber and friction tape. In October when the service box was entered to complete splicing to the adjacent set of aluminum mains, about a foot of steaming water was found in the box. Two cables were submerged and six were supported in racks above the water.

When the tape was removed from the ends of submerged aluminum conductors it was noted that about two inches had been corroded away and the ends of the strands were in needle points. Analysis of water in adjacent boxes showed small amounts of chlorides, sulfates, carbonates and bicarbonates.

Duplicated in Tests

Laboratory tests were conducted in which insulated aluminum conductors were suspended in a one percent sodium chloride solution with one end loosely covered with linen tape. When a 60-cycle potential difference of 40 volts was impressed across the conductors, causing 0.5 ampere to flow through the solution, about one-quarter inch of each conductor corroded away and aluminum strands were needle pointed. In another similar test with aluminum and copper cables, the aluminum conductor corroded. In like environment without current, there was no corrosion.

A tentative explanation is that during half cycle when the aluminum is at negative polarity, sodium hydroxide forms next to the aluminum. This dissolves aluminum's normally protective film and some of the aluminum. During the next half cycle the current flows from the aluminum into the electrolyte, thus removing some aluminum by electrolysis and partly reforming the film. In time the layer of corrosion products formed maintains an alkaline condition at the aluminum surface in spite of alternations of polarity.

Copper Reaction Differs

In the absence of current, aluminum is anodic to copper. When immersed in salt water galvanic current flows from the aluminum, through the electrolyte to the copper, resulting in corrosion of the aluminum anode. When alternating current is impressed between aluminum

and copper electrodes, flow of galvanic current may be neutralized by the larger current resulting from partial rectification of the AC. The current flow then is from the copper to the aluminum through the electrolyte.

This explanation appears valid concerning aluminum-to-aluminum and copper-to-aluminum currents in electrolytes containing sodium salts. It may not apply to other metals, such as lead. For example, lead sheathed cables of cross-bonded tie feeders have operated for many years with more than 12 volt 60-cycle sheath voltages vs earth without apparent damage.

High Silicon Anode Results Are Confirmed by Survey

Data from about 55 files on ground bed applications of high silicon cast iron anodes generally confirm the good results previously reported. This was the conclusion reached in the Second Interim Report (Tentative) on Use of High Silicon Cast Iron Anodes, prepared by Task Group T-2B-4 and presented at the March, 1957 meeting of Unit Committee T-2B. T-2B met also at Oklahoma City during the South Central Region meeting in October.

No conclusive data are available from tests underway using gypsum and wood fiber plaster backfills, except that poor current output seems to continue after two years. Inadequate tamping of coke breeze backfill or varying water tables seem to have little effect on high silicon iron anodes. Empirical formulae applied to beds installed without backfill appear to be substantially correct, but additional experience will be needed to prove them.

Horizontally installed cast iron anodes do not appear to perform to the single anode resistance formulae for anodes installed vertically. Furthermore, early evidence indicates molybdenum additions to high silicon cast iron will be helpful in severe conditions of operation. Principal gains from molybdenum appear to be when it is used in high temperatures. Most severe attack on cast iron anodes appears to be in the range 160-200 F.

These data will be given at greater length in a report to be submitted soon.

Redox Probe to Locate Microbiological Sites

A redox probe is under development now which may be used to locate probable sites where corrosion due to microbiological action may be expected, it was reported to Technical Unit Committee T-4B at Pittsburgh in November.

Task Group T-4B-5 expects to present for approval at San Francisco a questionnaire on corrosion control practices in the communication industry to parallel that recently completed on the power industry.

Polyvinylchloride Is Better In 4-Year Voltage Tests

Four-year tests reported by Task Group T-4B-4 on Protection of Pipe Type Cables indicate that plastic coatings on metallic sheathed cables sustain no significant loss in resistance to electrical currents on the order of one to 1½ volts. A progressive loss in resistance is reported when these voltages increase and the materials deteriorate markedly at 67½ volts DC. Of the materials tested polyvinylchloride is more resistant than Neoprene.

In tap water Neoprene jackets retained their integrity on voltage soak for four years at 1½ volts DC negative. In dilute acid they were all right at 1221 days when the jar was broken, ending the test.

There is a general tendency for the jackets to last longer in artificial sea water than in tap water because of lower vapor pressure of water over the salt solution. The tests showed also that positive DC voltages accelerated failure but at a rate lower than that caused by negative voltages. In short tests acetic acid and ammonia show considerable ability to damage the jackets.

Plastic Coatings Perform Well on Power Cables

Neoprene, polyethylene and polyvinyl chloride coatings on lead and aluminum-sheathed ducted and buried power cables perform well but have some deficiencies. This was the consensus of returns from a questionnaire circulated Task Group T-4B-4 on Protection of Pipe Type Cables in cooperation with the American Institute of Electrical Engineers. Of 35 companies queried, 22 replied by March 6, 1957 when the report was completed.

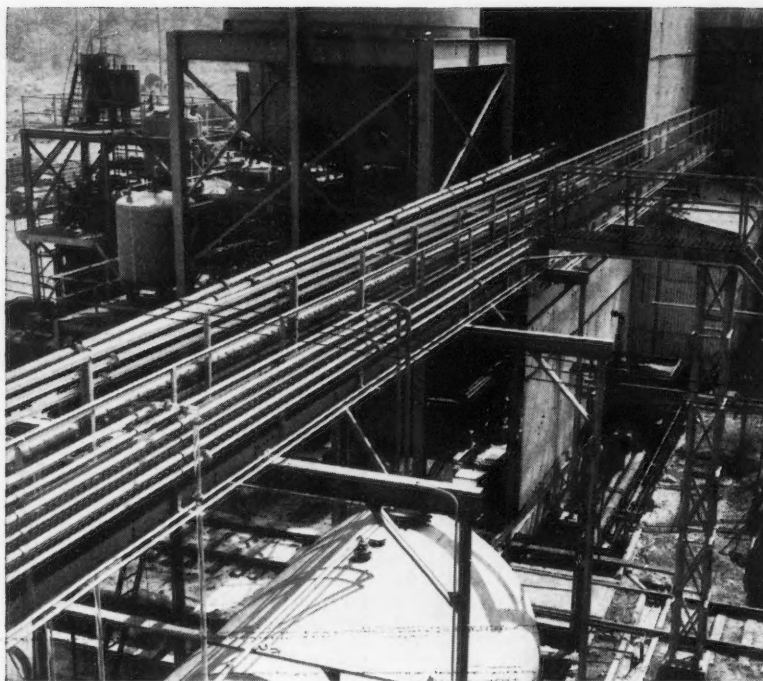
Duct lay cables showed difficulties in the following order of severity: Local galvanic cell action, 13 companies; chemical action, 6 companies and stray current electrolysis, 3 companies. These difficulties and others tabulated in the report caused the companies to use jackets for protection.

Only four companies use inhibited pulling greases, while 15 do not. Four companies use plain grease in the expectation it will reduce corrosion.

Among other things covered in this report are: Data on aluminum sheathed lay cable and installation data.

Graphite Anodes Salvaged

Of about 275 graphite anodes measuring 4 x 80 inches salvaged from ground beds along a pipe line in Texas, about 225 have been salvaged. Most appear in excellent condition. This information was given at a meeting in Oklahoma City in October 1957 of Unit Committee T-2B on Anodes for Impressed Currents.



TRUSCON CHEMFAST

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Corrosion Conditions!

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City _____ Zone _____ State _____

Urethane Foam Limits Cone Roof Tank Damage

Urethane foam applied as insulation for cone roof tanks holding oil products has the additional advantage of curtailing corrosion because it reduces condensation on roof and walls. This fact was reported at a meeting of Unit Committee T-2E at Pittsburgh in November.

Members of the committee reported that upper-ring corrosion is reported to be severe in Belgian Congo tanks and that the Gulf Coast of the United States has the same trouble. Some success with inhibition of static hydrocarbons was reported.

A Canadian pipeline is injecting aqueous solution of sodium nitrite at input station and adding solid sodium nitrite at 70-mile intervals to secure good protection when judged by the C factor.

A draft questionnaire on the corrosion of petroleum tanks was presented for consideration.

Tentative Minimum Plastic Tape Standard Prepared

Unit Committee T-2K, Prefabricated Plastic Film for Pipe Line Coating, discussed the progress being made by Task Group T-2K-1, Standards at their meeting November 12, 1957 in Pittsburgh. A tentative minimum standard has been developed and will be distributed to members shortly.

Draft copies of a questionnaire by Task Group T-2K-3, History and Results were distributed for discussion. Following a discussion it was decided to present it to the Technical Practices Committee for final approval.

A discussion was held on "Minimum Requirements for the Protection of Buried Pipe Lines" and several recommendations were made.

Central California Group Affiliates With T-7

Affiliation of Central California Cathodic Protection Committee with T-7E Western Region Corrosion Coordinating Committee brings the number of committees in the region to four. The new group, composed of underground plant operators in the San Luis Obispo-Bakersfield area, has C. J. Weir, Jr., Union Oil Co. of Cal., San Luis Obispo as chairman.

Zero Resistance Meter May Give False Readings

In some instances a false contact reading was experienced using the zero resistance ammeter, a meeting of T-4B-3 on Tests of Surveys was told in March, 1957 at St. Louis. Four members reported on the use of the instrument.

Project Group T-4B-3C completed its work by filing a list of reference material on the location of ground beds and proper testing procedures to prevent interference with other utilities.

NACE's Corrosion Abstract Punch Card Service issued 14,699 cards through 1957.

CORROSION's Technical Section published 190 more pages in 1957 than in 1956.



NACE NEWS

Corrosion Engineering Costs Is New York Topic



METROPOLITAN NEW YORK's December 11 Christmas meeting featured presentation to S. W. Shepard, Chemical Construction Corp. of a past chairman's certificate by NACE President W. H. Stewart, Sun Pipe Line Co. (both standing). Seated at the left are W. H. Kulman, Consolidated Edison Co. and A. F. Minor, American Telephone and Telegraph Co.

Stewart Stresses Importance of Corporate Members

Three thumbnail sketches on "Corrosion Engineering and Corrosion Costs" on telephone cables and in the chemical and electric-gas utilities were presented at the December 11 meeting of Metropolitan New York Section. This annual Christmas meeting at Hotel Shelburne was well attended despite snow, a strike on the subway system and the seasonal shopping rush.

W. H. Stewart, Sun Pipe Line Co., Beaumont, NACE president, spoke on "NACE Looks Ahead," stressing the current campaign to strengthen corporate membership and the many benefits NACE members get from their association. Mr. Stewart presented, on behalf of the section, a past chairman's certificate to S. W. Shepard, Chemical Construction Co., retiring chairman.

A. F. Minor, American Telephone and Telegraph Co. spoke on "Cable Corrosion Costs in the Bell System;" S. W. Shepard on "Controlling Corrosion in the Chemical Industry" and F. E. Kulman, Consolidated Edison Co., on "Corrosion Engineering in Electric-Gas Utilities."

New officers were elected as follows: N. N. Ehinger, Aluminum Company of America, New York, chairman; A. F. Minor, vice-chairman and B. C. Latting, Ebasco Services, Inc., secretary-treasurer.

Section meetings were scheduled as follows:

January 16—Chi-Am Chateau, Mountaintop, N. J. Speaker: T. J. Maitland, American Telephone & Telegraph Co., "Effective Cathodic Protection Systems."

February 20—Hotel Shelburne, New York City. H. R. Brownell, Sensitive Research Instrument Corp., "Instrumentation."

April 10—Chi-Am Chateau. Discussion on paints led by S. W. Shepard, Chemical Construction Corp.

A meeting will be held during May at a date to be determined later. A tour of an Alcoa plant is planned.

Plans Completed for 14th Annual Conference To Open in San Francisco on March 17

A well-rounded exhibit has been arranged, including many firms who have never heretofore participated in NACE exhibitions. The concurrent exhibition has been arranged with every reasonable effort being made to assure attention from registrants, including a full afternoon's schedule with no competing technical symposia. The exhibition is expected to be like other NACE exhibitions, well worth the time to visit and learn.

Broad Technical Basis

The formal symposia typify the broad technical basis of corrosion control that underlies NACE. Symposia on cathodic protection, chemical industry, high temperature reactions, utilities industry, oil and gas production, plastics, high purity water, marine corrosion problems, aircraft industry, pulp and paper industry, protective coatings, pipe lines, refinery problems, fundamentals and general inhibitors, corrosion problems will be held.

Also scheduled are four round table or discussion sessions on general corrosion problems, pipe line and under-

ground corrosion, refining industry and utility industry.

Technical Committee Sessions

Meetings of technical committees will cover many of the corrosion problems of most types of industries. Final decision will be made at several meetings on publication of findings of the committees and new measures taken to collect additional information.

Most technical committee meetings are open to NACE members and non-members alike. Some attending NACE meetings have said that more useful information is gained at meetings of the technical committees than elsewhere in like periods of time.

Social Side Remembered

Ample opportunity for social relaxation is provided. In addition to the separate program for ladies accompanying registrants, there will be the usual Fellowship Hour sponsored by the exhibitors, a banquet and dance and numerous other opportunities for after-hours entertainment in San Francisco.

NOTICE ON PAYMENT OF 1958 NACE DUES

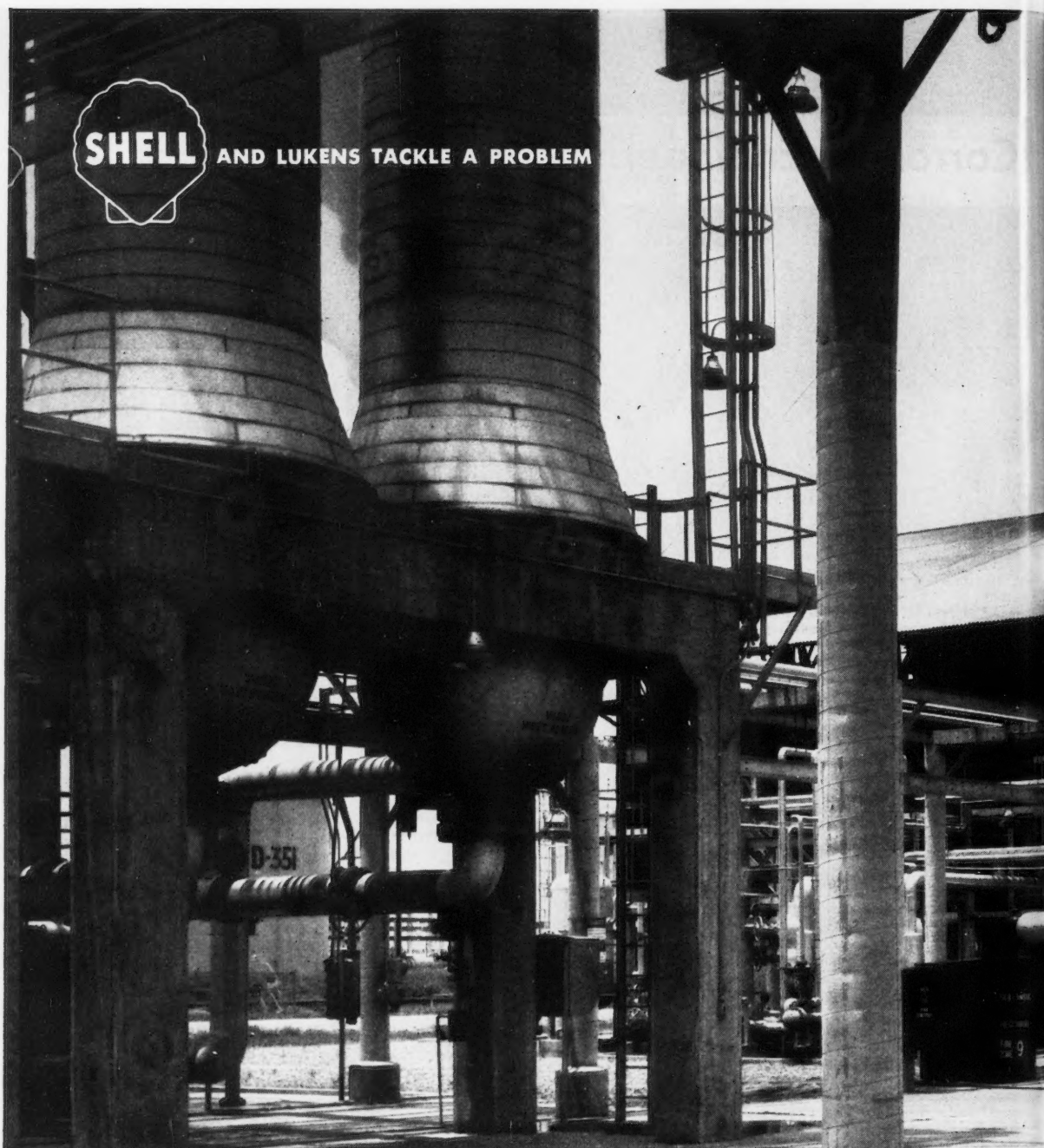
Invoices for 1958 membership dues have been sent to all Active and Junior NACE members. These dues are payable January 1, 1958. The NACE by-laws state that no member with dues in arrears for three months shall receive the publications of the association until such dues are paid.

* Accordingly the names of Active and Junior members whose 1958 dues have not been received by March 30, 1958 will be removed from the mailing list to receive CORROSION. No mailings of CORROSION will be made to delinquent members until dues are paid.

82 Exhibitors Contract For San Francisco Show

With the addition of three exhibitors to the roster previously announced (See CORROSION, February, 1958, Page 82 for an alphabetical list) the number of companies to show their products at the NACE 14th Annual Exhibition is 84.

Exhibitors who have taken space since the publication of the last list are: Oregon Metallurgical Corp., Albany, Oregon; Pacific Metals Company, Ltd., San Francisco, Cal.; Parker Brothers, Inc., Los Angeles, Cal.



Two 78" diameter Shell Vapor-Phase Hydrodesulfurizer reactors fabricated with Lukens stainless-clad steel.

Teamwork pays off—designing desulfurizers and Flued hemispherical heads answer need for uniform stress patterns

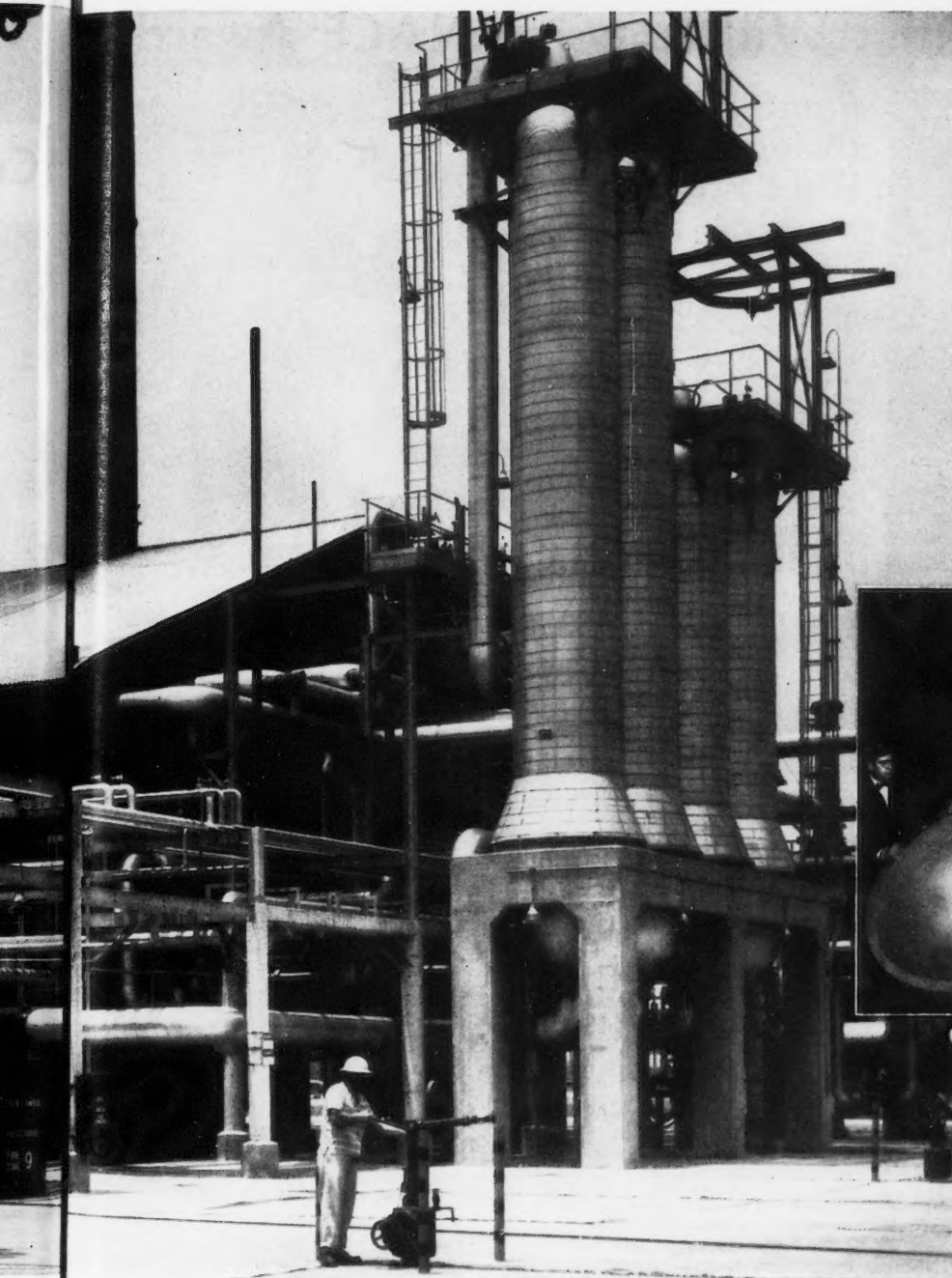
It took teamwork between Lukens and Shell . . . and at this modern Houston, Texas, refinery the results are rewarding.

There were separate problems in selecting steels for the Shell V-P Hydrodesulfurizers and Platformers and a common problem of obtaining a more uniform stress pattern in heads of both.

In the 78" diameter V-P Hydrodesulfurizer reactors, Lukens stainless-clad steel with a backing of Lukens A-204 firebox steel provided the required high resistance to hydrogen and hydrogen sulfide attack at elevated temperatures, plus strength and protection against hydrogen embrittlement.

In the 60" diameter Platformer reactors, where design pressure is 800 psi and design temperature is 950 deg. F., Lukens chrome moly steel plate gave still greater strength-temperature handling ability, plus resistance to hydrogen attack.

And by the use of Lukens hemispherical spun and flued heads in both the V-P Hydrodesulfurizer and the Platformer, engineers and production men



Four 60" diameter Platformer reactors of Lukens chrome moly steel.

Visit us at the
N.A.C.E.

Show in San Francisco,
March 18 through 20.
Our booth number is
35-37.



Smooth contours and accurate location of the flued openings in these Lukens spun heads matched Shell's critical design needs.

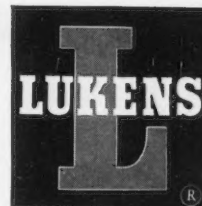
reformers with Lukens clad and alloy steels

achieved an outstanding advantage: Uniform stress patterns in the critical flued areas with added assurance of maintenance-free operation at high temperatures and pressures.

Ask your equipment builders about the broad range of Lukens clad, alloy, and carbon steels, or write for "CLAD STEEL EQUIPMENT." Address: Manager, Marketing Service, Room 127, Lukens Steel Company, Coatesville, Pa.



This is Lukens clad steel—a solid plate—one side corrosion resistant metal permanently bonded over-all to a rugged, economical backing steel.



Helping industry choose steels that fit the job

Hoar and Kuhn Will Receive NACE Awards



R. J. Kuhn

British Scientist, Louisiana Engineer Will Be Honored

The 1957 NACE Awards will be given to a distinguished British scientist and researcher on corrosion fundamentals and to a pioneer in the application of cathodic protection to underground structures. T. P. Hoar, since 1946 lecturer in metallurgy at Cambridge University, England will receive the Willis Rodney Whitney Award and R. J. Kuhn, corrosion engineer and consultant for New Orleans Public Service, Inc., New Orleans, La. will receive the Frank Newman Speller Award.

The awards will be presented during the Wednesday, March 19 annual banquet of the National Association of Corrosion Engineers at San Francisco. The association is holding its 14th annual conference there during that week.

Studied Under Evans

Dr. Hoar, who graduated from Cambridge in 1930, began research work on the fundamental mechanisms of corrosion under Dr. Ulick Evans, who received the 1948 Whitney Award. He received a PhD in 1933 for this work, and then began a series of researches for the International Tin Research and Development Council on the corrosion of steel, tin and tinplate.

During World War II he was engaged in corrosion control work for the British armed services and then and since has been consultant to large industrial firms. He has made two recent visits to the United States for lectures and discussions with corrosion workers and metallurgists.

Early Underground Control

Mr. Kuhn, a 1923 graduate of Tulane University, New Orleans in mechanical and electrical engineering was employed after graduation as an electrolysis engineer by New Orleans Public Service, Inc. During the interval 1923-36 he virtually halted the damage being done by electrolysis to his employer's underground structures such as water pipes, gas lines, electric, telephone and telegraph cables. As head of the Electrolysis Dept. of New Orleans Public Service he handled engineering problems associated with corrosion on 220 miles of electric railway track, six substations, about 800 miles of gas pipe, 800 miles of underground electric cables and 800 miles of water pipes.

When natural gas was brought to New Orleans in 1928, and new systems of welded steel mains from 2 to 20 inches in diameter were installed to deliver gas from the city gate to consumers in the city and in adjacent parishes, he conducted a pipe coating research program and operated two plants to coat about 50 miles of pipe. He also used stray current from the street railway system and current from rectifiers to protect these mains cathodically.

In 1931 he conducted electrolysis surveys of the United Gas Company and Houston Gas and Fuel Company lines and introduced cathodic protection to the systems.

Since 1936 he has been operating a consulting engineering service, retaining his connection with New Orleans Public



T. P. Hoar

Service. He has written and published many papers on underground corrosion control, been a lecturer at courses on corrosion, participated in National Bureau of Standards soil corrosion conferences and has been a member of corrosion committees of the American Gas Association for many years.

Young Author Award Goes to Two Pure Oil Co. Researchers



Marsh

Schaschl

Two researchers from the staff of the Pure Oil Company's Research and Development Laboratory at Crystal Lake, Ill., will receive the 1957 Young Author Award. The award will be given for their paper "The Effect of Dissolved Oxygen on Corrosion of Steel and on Current Required for Cathodic Protection," published in CORROSION's April, 1957 issue. Theirs was one of the 52 papers considered by the award committee headed by Prof. Norman Hackerman, University of Texas, Austin. It was the largest number of papers considered since the award was established in 1953.

Mr. Marsh, who has been working for Pure Oil since 1948 has a BS in chemistry from Illinois Institute of Technology (1945) and an MS in chemistry from Northwestern University (1946).

Mr. Schaschl, who joined Pure Oil in 1948 as a process engineer has a BS in chemical engineering from Illinois Institute of Technology.

Both authors are frequently contributors of literature on corrosion control matters to CORROSION and other technical periodicals. They will receive the \$50 gratuity during the annual NACE banquet at San Francisco, Wednesday, March 19.

Punch Card Service Personnel Changed



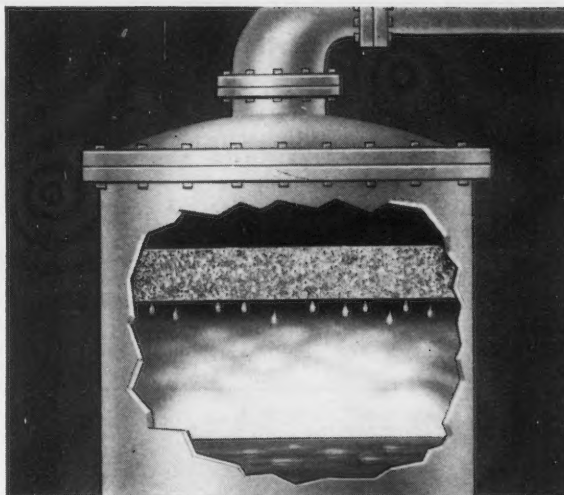
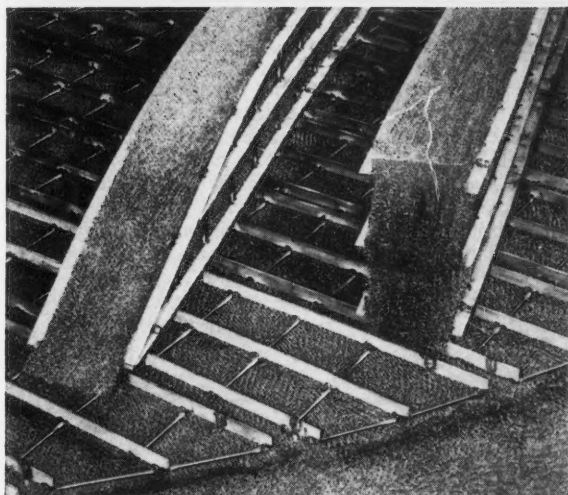
Humphrey

Treves

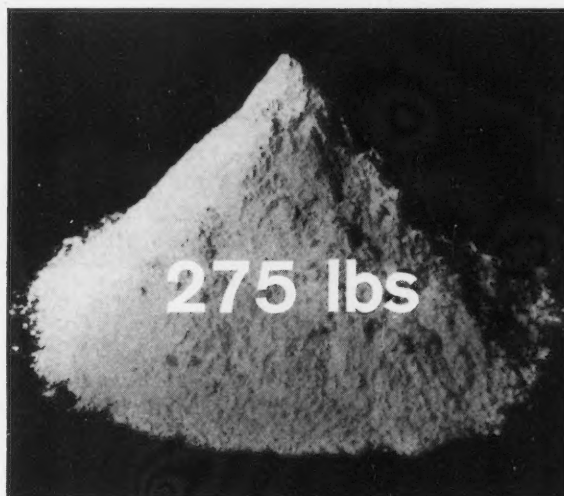
Miss Nicole Treves, born and educated in Cairo, Egypt, will be in charge of the NACE Abstract Punch Card Service and its associated abstract publication work beginning in March. She replaces Miss Agnes Humphrey, who has been in charge of the work since June, 1953. Miss Humphrey is leaving NACE employ to marry Frank T. Wyatt, with the Defense Research Laboratory, Austin, Texas. The couple will live in Austin.

Miss Treves, of French and Italian parentage, received her education at Lycee Francais de Caire and at American University of Cairo where she received a BS in chemistry with a minor in sociology in 1956. Since 1953 she has been doing part time work on the JOURNAL D'EGYPT, a French language daily newspaper in Cairo and on the weekly news magazine IMAGES. She was em-

(Continued on Page 70)



Nickel wire mist eliminator...in 8½-foot evaporator...



Stops corrosion of 30-inch vapor line...

and saves \$8 worth of NaOH per day

Costly carryover of corrosive liquids entrained in vapor can be stopped easily and economically with Nickel Alloy wire mist eliminators.

That was proved again very recently by the experience of Frontier Chemical Company, a Division of Union Chemical and Materials Corp.

Frontier concentrates some 50 tons per day of 50% NaOH in an 8½-foot evaporator. Caustic carryover from the evaporator was causing an \$8 per day loss in product and expense of neutralization. The 30-inch vapor line was corroding badly, too, and expen-

sive replacement was just around the corner.

Separators ruled out on costs

Frontier's engineers looked into several separator devices but the knitted Nickel wire mist eliminator shown above cost less than half as much. It requires no major change in the vessel and can be installed through the manhole. The pad provides about 100 square feet of droplet collection area per cubic foot but reduces free volume by less than 3%. The Nickel insures against corrosion and contamination problems.

Four trouble-free years

Frontier reports that the only maintenance required in four years has been a twice-weekly 30-minute backwash with water to remove solid particles.

Are you having trouble from carryover of corrosive chemicals? Write for a list of mist eliminator manufacturers.

The International Nickel Company, Inc.
67 Wall Street New York 5, N. Y.



INCO NICKEL ALLOYS

Nominations for the 1959 Whitney and Speller Awards

The Willis Rodney Whitney Award is given in recognition of public contributions to the science of corrosion. A contribution to science is defined as the development of new information or the development of a more satisfactory theory which contributes to a more fundamental understanding of corrosion phenomena.

The Frank Newman Speller Award is given in recognition of public contributions to corrosion engineering. A contribution to engineering is defined as the development or improvement of a method, apparatus or material by which the control of corrosion is facilitated or made less costly.

Nominations may be made by local sections or may be proposed directly to the Chairman of a Region by individual members up to June 1, 1958. In any case, nominations should be accompanied by an appropriate statement of the basis of the proposal.

Procedure in the Selection of Persons to Receive these awards was published beginning on Page 98 of the March, 1956 issue of Corrosion, or anyone interested may get a copy by writing to Central Office NACE, 1061 M & M Bldg., Houston 2, Texas.



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NATIONAL and REGIONAL MEETINGS and SHORT COURSES

1958

Mar. 17-21—NACE Annual Conference,
Civic Auditorium, San Francisco,
California.

Oct. 5-8—Northeast Region, Somerset
Hotel, Boston, Mass.

Oct. 15-17—North Central Region. Cin-
cinnati, Ohio.

Oct. 20-24—South Central Region. New
Orleans, Roosevelt Hotel.

1959

March 17-19—15th Annual Conference
and Exhibition, Sherman Hotel, Chi-
cago.

Oct. 12-15—South Central Region Meet-
ing, Denver, Col.

SHORT COURSES 1958

April 1-3—University of Oklahoma Corro-
sion Control Short Course, Norman.

June 4-6—Teche Section Second Annual
Short Course on Corrosion. South-
western Louisiana Institute, Lafay-
ette, La.

Punch Card—

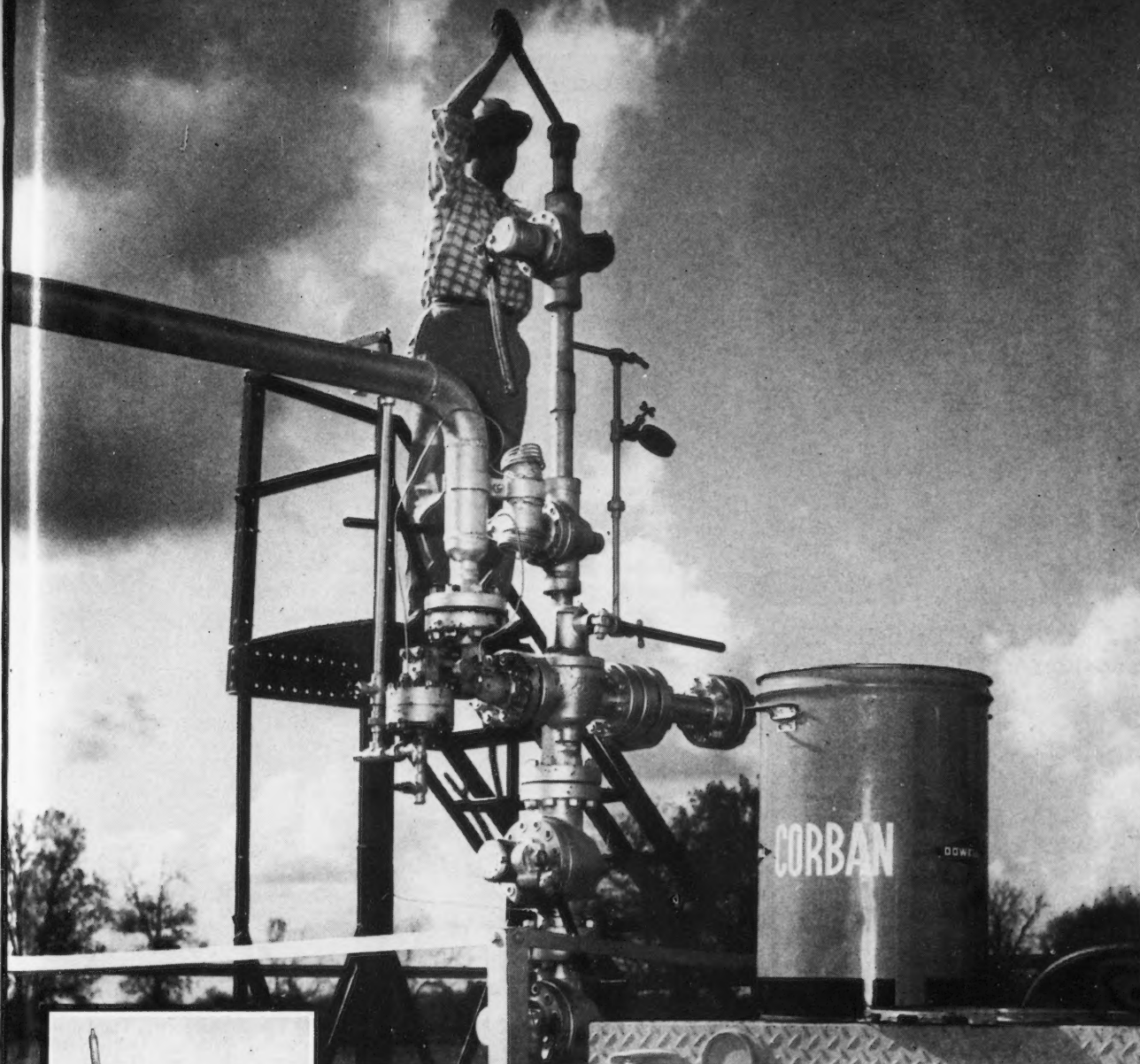
(Continued From Page 68)

played full time as a journalist from July,
1956 to November, 1957. She continues
as correspondent for the two publica-
tions.

She speaks French, Italian, Arabic
and English and reads English and
Spanish. Her interests include journal-
ism, amateur theatricals and piano music.

Miss Humphreys, a graduate of the
University of Texas with a BA in chem-
istry and a student at University of
Houston, besides her work with the
punch cards also has edited and com-
piled two volumes of the NACE Biblio-
graphic Survey. She is interested in art,
sports cars and writing and is a member
of American Chemical Society and Spe-
cial Libraries Association.

NACE's Corrosion Abstract Punch Card
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STICKS OF CORBAN — TO GIVE CORROSION PROTECTION IN SPECIAL WELLS.

In wells where the application of Corban® corrosion inhibitor in liquid form is either impossible or impractical, Dowell offers Corban *in stick form*. Stick Corban is packaged in air-tight, weather-proof metal drums, with handles for ease of handling.

These cylindrical sticks are introduced into the tubing through lubricators or pressure locks. On reaching the bottom, the sticks melt and dissolve slowly in the well fluids. Production then carries the Corban inhibitor back up the tubing to coat and protect the metal surfaces of the well, Christmas tree and flow lines. Stick Corban is available with melting points from 140° F. to 280° F.

Both concentrated and ready-to-use liquid Corban are available in addition to Corban sticks. All forms of Corban are provided in several formulas to fight corrosion on any type well. Call any of the 165 Dowell offices in the United States and Canada for an engineered recommendation on the use of Corban. In Venezuela, contact United Oilwell Service. Dowell, Incorporated, Tulsa 1, Oklahoma.

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Willis R. Whitney, First to Receive NACE Science Award, Succumbs at Schenectady



Willis R. Whitney

NACE Will Have Booth

As usual there will be a booth in the exhibition at San Francisco for the National Association of Corrosion Engineers. It will offer copies of NACE publications, lists and other information about NACE and its activities.

When Willis R. Whitney moved into Steinmetz' barn at Schenectady no one could foresee that the General Electric Company's laboratories would develop in 30 years to an institution with a staff of 1300. Dr. Whitney, who died January 9 at 89 years of age following a heart attack, was first director of the laboratory and first recipient of the National Association of Corrosion Engineers Award for achievement in corrosion science. The award, given to him in 1947, is named after him.

He is credited generally with development of the electrochemical theory of corrosion while a professor of chemistry at Massachusetts Institute of Technology. Educated at MIT and at University of Leipzig, from which he received a PhD in chemistry in 1896, he began his teaching career at MIT, where he retained his position as nonresident professor of chemical research until his death.

Became Laboratory Head

He was employed in 1900 by the then President E. W. Rice of General Electric to work with Dr. Charles Steinmetz, with the promise he would be given freedom to continue his work in any field he wished. From 1900 to 1932 he was active director of the research laboratory and continued research as consultant after his retirement from that post and from the post of vice-president in charge of research in 1941.

The General Electric Research Lab-

oratory is reputed to be the first industrial laboratory established in the United States devoted to basic research. During the years when Dr. Whitney was its director many important technical discoveries were made in it. These included fundamental discoveries in radio tubes, cathode ray devices, submarine detectors used in World War I and other developments related to lightning, high voltage x-ray apparatus, turbines and many others.

Honored Many Times

Dr. Whitney was honored many times by schools and scientific organizations. He was a member of the National Academy of Sciences, National Research Council, American Chemical Society, The Electrochemical Society and many others. He was a president of both the ACS and ECS. He received numerous honorary degrees and the Willard Gibbs Medal, Chandler Medal, Perkin Medal, Franklin Medal, Edison Medal and others.

He is survived by his widow and one daughter.

Underground Corrosion Is Magnet at Boston

Underground corrosion proved a topic of sufficient interest to induce attendance of 32 members and 19 guests including several visitors from Maine to the January 22 meeting of Greater Boston Section. Some drove 100 miles and back from Portland in heavy fog to attend.

Donald B. Pike, Stone and Webster Eng. Corp. acted as moderator for a panel discussion on underground corrosion among Elliott R. Perkins, New England Telephone and Telegraph Co.; Albert J. O'Neil, Bethlehem Steel Co., Quincy and D. J. Allin, New England Power Service, Worcester. Mr. Perkins is chairman of Greater Boston Electrolysis Committee, a function of NACE's T-7 Corrosion Coordinating Committee.

Mr. Perkins described some of the problems met by the Boston committee involving underground structures of oil and gas companies, electric companies, water systems and telephone and telegraph companies; First Naval District, Department of Public Utilities and Metropolitan Transit Authority. The Boston group is among seven in NACE's Northeast Region affiliated with T-7.

Mr. O'Neil's remarks related principally to problems associated with street railway stray currents and galvanic corrosion. He reviewed control devices and precautions. Mr. Allin summed up the comments technically and showed slides of cathodes attacked by departing currents.

Other business of the meeting included a review of the coming technical program for the NACE conference at San Francisco and a summary of plans for the October 5-8 Northeast Region Conference at Boston.

Kenneth Barclay, Electro-Rustproofing, Ltd., London, England was a guest of the section.

Alamo Section Elects

Zane Morgan has been elected chairman of Alamo Section for 1958. Other officers to serve are as follows: Ransom L. Ashley, United Gas Pipe Line Company, vice-chairman, and J. C. Kneuper, City Public Service Board, secretary-treasurer. Carl M. Thorn remains as trustee of the section.

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Acid	Excellent
Alkali	Good
Solvent	Poor

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A thermally cured coating that resists acids, solvents and alkalis

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Solves many problems of chemical corrosion. For lining tanks, tank cars, pipes, food containers, storage bins, fans, ducts, hoods, etc. at moderate cost. Made by a company specializing in corrosion resistant coatings. Not a side line. BISONITE products in many cases have corrected conditions when other coatings have failed. Write for descriptive literature. Our nearest approved applicator will be glad to give your coating problems immediate attention.



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For piping acids, alkalis, solvents and other corrosive fluids specify saran lined pipe, fittings, valves, and pumps with the new gray lining. This new lining anchored under pressure within the steel casing, enables you to pipe fluids over a wider range of temperatures than ever before . . . with maxi-

mum protection from corrosion, plus the strength of steel.

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If your operation can benefit from a *complete* corrosion resistant piping system, write today for more information about saran lined piping components. And be sure to ask about Saraloy® 898 tank lining, too! THE DOW CHEMICAL COMPANY, Midland, Michigan.

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D E A T H S

Alfred C. Buensod, president of Buensod-Stacey, Inc., New York City cooling tower, water treatment and protective coatings firm died November 25 at Scarsdale, N. Y. Mr. Buensod, an NACE member since 1950, was a graduate of Stevens Institute of Technology and a registered professional engineer in a number of states. He had been in corrosion control work for some 28 years at the time of his death.

W. Roy Chadburn, executive vice-president of Chadburns (Canada) Ltd., Toronto, Canada died July 8. He was a member of the U. S. Society of Naval Architects and Marine Engineers, and Northeast Coast Institution of Engineers and Shipbuilders (Britain). He joined NACE in 1956.

John P. Dick—John P. Dick, an employee of Magnesium Company of Canada, Ltd., Montreal, died several months ago. A 1926 graduate in mining engineering of the University of Toronto, he joined NACE in 1954.

E. F. Fellows—Edward F. Fellows, district manager for National Aluminate Corp., Houston, a member of NACE since 1955, died August 1. He had nearly 30 years experience in corrosion control work.

L. C. Flickinger—Chief Chemist, Campbell Works, Youngstown Sheet & Tube Co., Youngstown, Ohio, died July 17. Mr. Flickinger, a member of NACE since 1947, worked on the corrosion control problems of steel plants for more than 20 years. He was an alumnus of Ohio State University.

Mark K. McIlvane, associated with Chanslor-Canfield Midway Div., Chanslor-Western Oil and Development Co., Los Angeles, who joined NACE in December, 1953 died recently. He was active in control of down-hole well corrosion and cathodic protection of tanks.

J. E. Steigerwald, Baltimore representative for Federal Paint Co. died suddenly December 7. He had been engaged in corrosion work 16 years, including 12 years of ship bottom inspection.

Joseph W. Thompson, an employee of Koppers Company's Tar Products Division at Buffalo, died November 6. When he joined NACE in 1953 he had six years' experience in corrosion control work.

S. M. Vile, engineer with Pennsylvania Railroad Company, Philadelphia died while on a trip in North Carolina September 3. He had been in active direction of the railroad's electrolysis mitigation for many years. He joined NACE in 1948.



SPECIAL DELIVERY for liquids and gases in all branches of industry is assured with Kraloy Rigid Polyvinyl Chloride (normal and high impact) Plastic Pipe... with virtually no maintenance or policing. You install Kraloy PVC—and forget it. That's why millions of feet of Kraloy Plastic Pipe are in use today, because Kraloy PVC is inert and can never rust, rot, or corrode, is not subject to electrolytic action, handles abrasives, slurry and most Ph factors, is scale resistant. Superior flow characteristics (C factor = 150+) permit use of smaller diameters. Installation costs 50% less, due to light weight and ease of handling.



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Plans for South Central Region Conference Pushed

The October 20-24 conference of NACE's South Central Region at New Orleans' Roosevelt Hotel will be held in the center of one of the fastest growing industrial complexes on the Gulf Coast. The rapidly expanding industrial development of the New Orleans area, which scores of huge plants lining the Mississippi River on both sides for miles, will be an added attraction for the conference.

NACE registrants will have an opportunity to see the new Mississippi River bridge now under construction, and may ride over the recently completed 24-mile causeway that connects the city with St. Tammany parish vacation lands across Lake Pontchartrain.

New Orleans' vast port facilities are being expanded by construction of a Tidewater Ship Channel to connect the city with the Gulf of Mexico. Ships presently must negotiate shoals at the mouth of the river and the river for more than 100 miles before reaching the city.

Port and harbor frontage measures more than 50 miles along the river and some 11 miles along the Inner Harbor Navigation Canal which connects the river and Lake Pontchartrain. The city and state have spent more than \$23 millions on the harbor since 1952 and plan to spend \$72 millions more in the next 10 years.

New Orleans has more than 800 manufacturing plants employing more than 50,000 persons. It also has one of the two United States Foreign Trade Zones, where commodities may be held and re-worked duty free unless they enter domestic commerce.

New Orleans is noted also for the variety of its entertainment opportunities. These range from outdoor sports of all kinds, including boating, to the numerous night entertainment spots and internationally known eating places.

The city has many modern hotels and motor courts and is accessible readily by numerous good highways, railroads and major air routes.

Treseder Is Publication Committee Vice-Chairman

R. S. Treseders, Shell Development Co., Emeryville, Cal., a member of the NACE board of directors and active in technical committee work has accepted the position of vice-chairman of the NACE publication committee. It is anticipated Dr. Treseder will succeed as chairman Dr. T. P. May, International Nickel Co., Inc., who has held the post for the past two years.

Marc Darrin Resigns

Marc Darrin, Mutual Chemical Div., Allied Chemical & Dye Corp., Baltimore has resigned from the NACE Editorial Review Subcommittee.

The 1959 15th Annual NACE Conference will be held in Chicago.

Using impressed current anodes?



GRAPHITE ANODES ARE BEST!

FOR LOW COST...

"National" graphite anodes provide ample conductivity for economical ground bed design in both low and high resistance soils. Installed with graphite particle or coke backfill, "National" anodes offer low initial cost; exceptionally long life.

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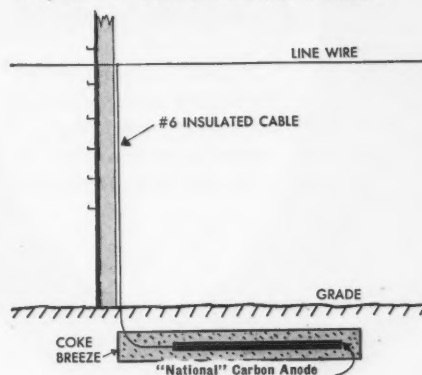
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Type QA Anodes of NA Graphite

If you do not use "National" Graphite Anodes for cathodic protection, try them! We believe you'll find

**"NATIONAL" GRAPHITE ANODES ARE BEST
FOR LONG LIFE AND LOW COST!**

FOR LONG LIFE...

15 years of service without a leak!



Since 1943, a distributed "National" carbon anode system has protected 2042 feet of 4 inch bare steel main for a large Eastern utility company. Installed horizontally (see diagram) to avoid shale rock, 16 - 2" x 80" anodes are spaced approximately 120 feet apart to obtain uniform protection.

Before installation of the "National" carbon anodes, 4 leaks occurred on the main in one year. Since cathodic protection began in October, 1943, there has not been a single leak.

INSTALLATION DATA

Anode size: "National" 2" x 80" Carbon

Backfill: Coke breeze

Length of anode service: 15-30 ampere-years
per anode

Average soil resistance: 1000 to 10,000
Ohm. cm.

The terms "National" and "Union Carbide" are registered trade-marks
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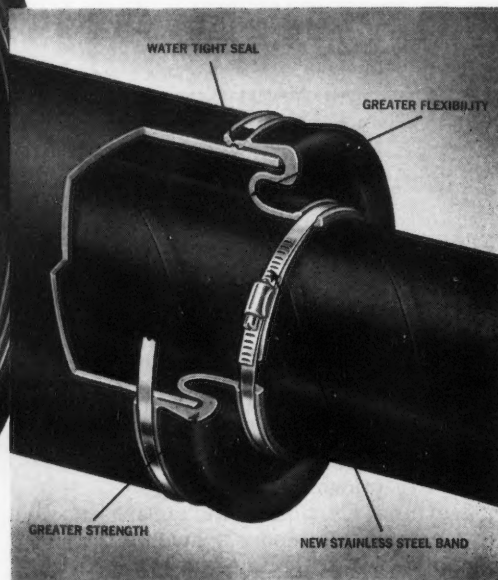


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New
Plico Molded
BUTYL RUBBER
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Casing Seal

*Provides a Permanently
 water tight seal and greater
 latitude for both lateral and
 longitudinal movement of
 the pipe and the casing*



Easier Installation, Lower Cost
Long Life Butyl Rubber or Neoprene
Water Tight Sealing

A GREAT ADVANCEMENT IN CASING SEALS

Greater flexibility where it counts — By the use of a pre-molded expansion section that fits up inside the casing, the Plico Casing Seal is more flexible, which provides greater latitude for both lateral and longitudinal movement of the pipe in the casing. The use of a new 100% Butyl Rubber special compound that provides the most flexible material possible consistent with maximum durability. The greater resilience of this material enables it to fill irregularities on the O.D. of the casing or coated surfaces of the carrier pipe, thus insuring maximum sealing against moisture intrusion and longer life expectancy of the carrier pipe and casing.

Greater thickness in the critical area — In the area of the edge of the casing pipe, where there is the greatest potential mechanical damage due to backfill, the increased (2-1/2 times) material thickness of the fold eliminates the need for a rock shield in almost all cases.

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 Steel Bands**

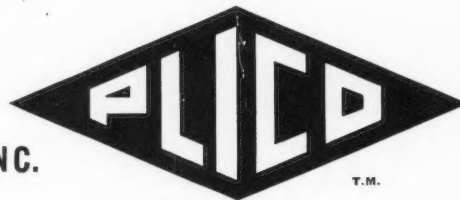
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Easy Installation

— This Screw Type Band goes on like a hose clamp. The only tool required is a screwdriver.

Greater Safety

— The protective Shoe or compression ribs makes possible 100% circumferential contact, thereby reducing the possibility of mechanical damage from the band and assures a positive seal.



T.M.

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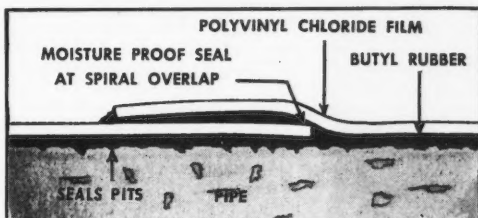
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Now superior PLICOFLEX Laminated Tape Pipeline Coating is available at the price of ordinary tape coatings, and costs less than the most economical hot coatings.

Check these outstanding advantages:

1. The exceptionally strong bond typical of PLICOFLEX Tapes is now available in this new low cost tape coating.
2. PLICOFLEX Tapes, including the 14 mil, provide a continuous Butyl Rubber Coating over the entire surface of the pipe. This is illustrated by the drawings showing the continuous Butyl Rubber Film at the overlap. Because of its desirable cold flow characteristics, the especially compounded butyl rubber fills all the space in the helix of the overlap, resulting in a homogeneous and continuous butyl film.
3. The physical toughness of the Polyvinyl Chloride Film to which the Butyl Rubber is laminated provides protection against abrasion plus sufficient



strength to wrap under tension, which causes the Butyl to fill the pits and depressions on the pipe. This physical strength makes it possible to apply the Tape over the ditch at high speed by machine, by yard or railhead spinning rigs, or by hand.

4. The recognized chemical resistance and stability of the Polyvinyl Chloride Film provides additional protection from chemical attack by most corrosive environments.

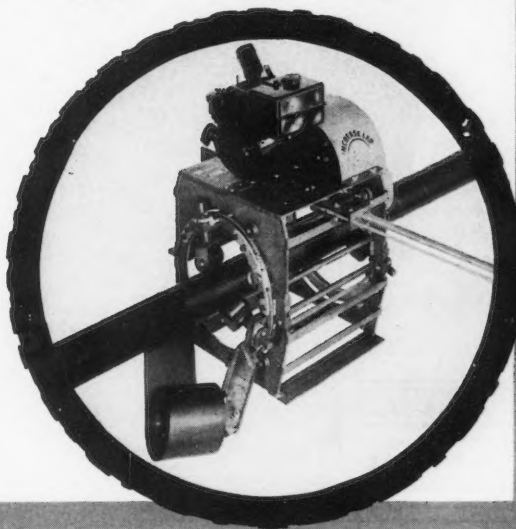
Superior Plicoflex Pipeline Coating now available to all

The low cost of PLICOFLEX Tape coupled with its adaptability to hand or machine application provides an economical protective coating which is highly resistant to corrosion and is within the reach of even the most limited budgets. This fact, coupled with Plicoflex low cost spinning rigs, makes it ideally suited for companies unable to build and operate a standard or large coating facility.

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—4 Types to Choose From—

340-14	7 Vinyl	7 Butyl
340-25	10 Vinyl	15 Butyl
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Corrosion Panel Held At Buffalo Fair

A four-man panel discussed corrosion on the evening of February 20 during the Industrial, Engineering and Science Fair at Buffalo's Memorial Auditorium February 18-20. Members of the panel and their topics were: M. G. Fontana, Ohio State University, Columbus, sponsored by The Duriron Co., "Unusual Corrosion Problems;" R. Folkman, Electro Metallurgical Division, Carbide and Carbon Chemicals Co., "Titanium;" W. E. Kuhn, Carborundum Metals Co., "Zirconium;" C. G. Kiplinger, National Aniline Div., Allied Chemical & Dye Corp., "Urethanes."

Dr. Fontana also discussed with students educational requirements of a corrosion engineer.

At a booth in fair effects of corrosion were displayed along with means of mitigating it. Promotional literature of NACE also was available.

In cooperation with Western New York Science Congress, Niagara Frontier Section, which manned the booth and sponsored the corrosion program, donated \$100 in prizes. To the best project on corrosion in the senior division lecture demonstration \$50 was given. Plaques, medals and cash awards were made in the Junior division lecture demonstrations and exhibits.

Responsible educational committee members from Niagara Section are: E. H. Caldwell, Hooker Electrochemical

Co., chairman; H. A. Andersen, Carborundum Metals Co.; M. Stern, Electro Metallurgical Div., Carbide and Carbon Chemicals Co.; E. K. Benson, New York Telephone Co.; R. M. Jordan, Calgon Co. and W. A. Szymanski, Hooker Electrochemical Co.

Canadian Region Elects B. H. Levelton

B. H. Levelton has been elected chairman of Canadian Region, H. G. Burbidge, vice-chairman and W. G. Brander, secretary-treasurer. Mr. Levelton, associated with British Columbia Research Council, Vancouver, is a chemical engineer. He was graduated with an MA in Sc in Chemical Engineering from the University of British Columbia, and later received a PhD, also in chemical engineering.

Mr. Burbidge, employed by Aluminum Company of Canada, Montreal, directs the company's Corrosion Section in its General Engineering Department. He has a BSc in chemical engineering from Queen's University.

Mr. Brander, Corrosion and Transmission engineer with Northwestern Utilities, Ltd., Edmonton graduated in chemical engineering from University of Alberta.

W. A. Webster, named membership chairman, currently is chairman of Toronto Section and is general manager of Corrosion Service Ltd., Toronto. He is a graduate in electrical engineering of University of Toronto.

West Kansas Section Elects G. H. Fanshier

At a special called meeting of West Kansas Section January 9, new officers for 1958 were elected as follows: G. H. Fanshier, Corrosion Rectifying Company, chairman; Roy Junkins, Cities Service Oil Company, vice-chairman; Ray Walsh, Aquaness Dept., Atlas Powder Company, secretary-treasurer. W. C. Koger, Cities Service Oil Company, will continue as trustee.

A membership committee consisting of Sam Burnell, Nacor Chemical Company, Tom Allan, Allan Pump & Supply Company and Robert O. Faris, National Cooperative Refinery Association were appointed to add members to the section and to secure corporate members for NACE. The section also appointed an educational committee headed by Edward Capehart, Petroleum Inc.

West Kansas Section meetings are scheduled for the first Thursday of each month at the Parrish Hotel at Great Bend, Kansas.

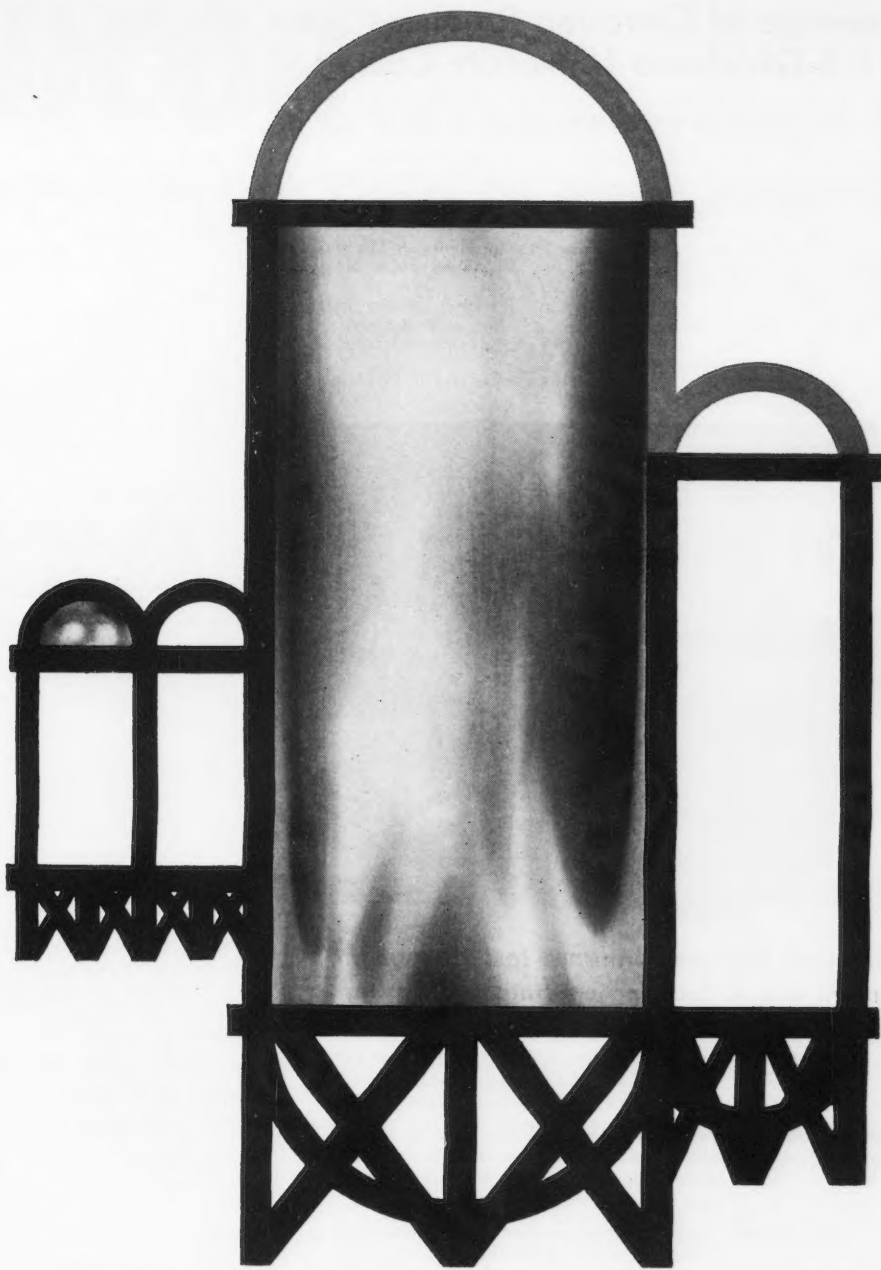
Garrett Is New Chairman Of Birmingham Section

William W. Garrett has been elected chairman of Birmingham Section for 1958. The following new officers have been elected also: Ralph M. Cunningham, Steele & Associates, Inc., vice chairman; John B. Paisley, Jr., American Tel. & Tel. Company, secretary-treasurer; and Marion M. Fink, Tennessee Coal & Iron Division, U. S. Steel Corporation, Electrical Laboratory, assistant secretary-treasurer.

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Alcoa's corrosion specialists have accumulated over 1000 man-years' experience applying aluminum to solve corrosion problems in the process industries. Their un-

equaled experience has produced an immense fund of factual data on the behavior of aluminum with corrosive materials and in corrosive atmospheres. That data is at your service.

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Visit Alcoa's Booth No. 40-42
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San Francisco, March 17-21


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Alternate Monday Evenings



Specify Alcoa Aluminum for
corrosion-free Process Equipment
Pipe & Tube
Tanks, Containers, Trucks & Cars
Plant Structures

Broad Coverage of Corrosion Problems Set At April 1-3 Oklahoma University Course

Broad coverage of the corrosion problem in discussions ranging from atomic energy to paints is scheduled for the April 1-3 Corrosion Control Short Course to be held by University of Oklahoma at Norman. Central Oklahoma Section NACE is cooperating with the university in presenting the course.

Among the topics for which speakers have been arranged are the following:

Aims and Achievements of NACE, J. C. Spalding, Jr., Sun Oil Co.
Fundamentals of Corrosion, Parke D. Muir, Dowell, Inc.
Integration of Corrosion, Leakage and Maintenance in Gas Distribution

Systems, O. W. Everett, Oklahoma Natural Gas Co.

Surveying for Cathodic Protection, James R. Cowles, consultant.

Rectifiers for Corrosion Control, T. P. Wilkinson, Holcombe Co.

Corrosion and Safety, Leo King, Shell Oil Co.

New Developments in Maintenance Protective Coatings, John Nee, Briner Paint Mfg. Co.

Alerting Foremen to the Importance of Recognizing and Reporting Corrosion, W. A. McCarthy, Phillips Petroleum Co.

Corrosion Control in Gasoline Plants,

I. A. Peterson, Phillips Petroleum Co. Corrosion Control in Gas Recovery Absorbers, M. J. Olive, Arkansas Fuel Oil Corp.

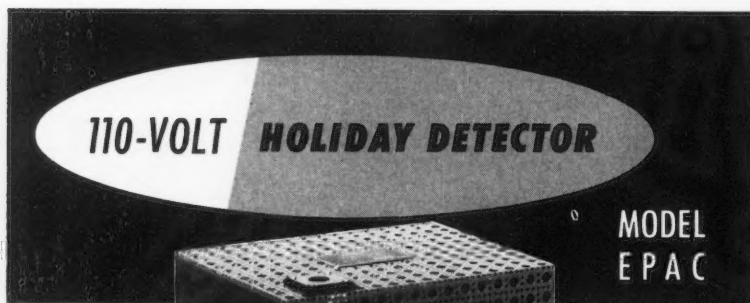
Corrosion Resistance of Metals vs. Environment, W. R. Upthegrove, University of Oklahoma.

Aromatic Polycarbonate Resins; New Rugged Plastics, K. B. Goldblum, General Electric Co.

Selecting Paint and Maintenance Coatings for Service, R. M. Robinson, Continental Oil Co.

Corrosion in the Atomic Energy Industry, J. E. Draley, Argonne National Laboratory.

Other topics to be discussed are elements of inhibitor protection, elements of cathodic protection, squeeze treatments, corrosion problems in high pressure gas condensate wells, internal coatings for pipe, waste water disposal, cathodic protection of oil well casings, pipe coatings and plastic tape.



Economical, high-performance test instrument for plant use in locating coating perforations

ADJUSTABLE VOLTAGE REGULATOR

This instrument is designed for use at permanent pipe yards or railheads using 110 to 115 volt AC power. Voltage output can be adjusted externally in a range from 5000 to 20,000 volts.

EASILY PORTABLE

Detector unit in metal case with lift handles weighs but 13¼ pounds and is easily carried by one man. It can be set near the work or may be used with electrodes on long cords.

BELL SIGNAL

When an electrode attached to this detector finds a "holiday," scratch, hole, burned or coked spot in pipe wrappings its sharp, pulse-type voltage grounds on the pipe and signals the operator by a prolonged ringing of a bell.

MANY TYPES OF ELECTRODES

Unit may be ordered with Tinker & Rasor spring electrodes (either half or full circle), new non-fouling, conductive, silicone rubber flat blades on wand handles or wire brush type.

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March

- 4 Montreal Section. Queen's Hotel, Montreal, Jason J. Waller, Canadaair, Ltd., speaker.
- 11 Shreveport Section. Washington-Youree Hotel, Shreveport.
- 18 Chicago Section. Use and Application of Aluminum and Aluminum Alloys in the Oil and Chemical Industries, R. W. Flournoy, Reynolds Metals Co.
- 24 New Orleans-Baton Rouge Section. Engineers Club, DeSoto Hotel, New Orleans.
- 24 Tulsa Section. Mayo Hotel, Tulsa.
- 25 Southwestern Ohio Section. Hamilton, Ohio. Sponsored by Champion Paper Co. Subject: Paper Industry Corrosion.

April

- 1 Shreveport Section, Washington-Youree Hotel.
- 10 Metropolitan New York Section. Chi-Am Chateau, Mountinside, N. J. Instrumentation, H. R. Brownell, Sensitive Research Instrument Corp.
- 15 Chicago Section. Metallurgical Aspects of Corrosion.
- 15 Cleveland Section. J. J. Harwood, U. S. Naval Research Laboratory, Washington.
- 28 New Orleans-Baton Rouge Section. Engineers Club, De Soto Hotel.
- 28 Tulsa Section. Mayo Hotel.
- 19 Southwestern Ohio Section. Dayton, Ohio. Sponsored by Dayton Power & Light Co.

Oak Ridge Discussion Is Held on Inhibitors

G. H. Cartledge, Oak Ridge National Laboratory is to give a talk on corrosion inhibitors at a meeting of East Tennessee Section at Ridge Recreation Hall, Oak Ridge during April.

D. D. Stone, The Duriron Co. was the scheduled speaker at a February 24 dinner meeting at the Dwarf Restaurant, Knoxville on "High Silicon Iron in Chemical Service." Other meetings of the section will be held during the year.

UNICOR[®] keeps corrosion from eating a big hole in your profits



Talk about money down the drain! Look at the ways corrosion can lose you money:

1. Reduced flow capacity means less volume handled per day. Corrosion in your pipeline takes up money-making space, reduces C factor and output.
2. Filters cost money. Take a look at your filter replacement cost sheet for the past year and you'll see what we mean.
3. Downtime for filter cleaning and replacement is a dead weight on overhead. You're not making money when you're not on stream.
4. Equipment replacements aren't cheap, either. When corrosion takes over tanks and pipelines, you're out-of-pocket for new ones.

And now look at the ways UNICOR saves your money and your equipment:

1. Unicor is a film-forming, oil-soluble inhibitor that prevents all types of pipeline corrosion. Tanks, vessels, pipelines are protected whether full, half-full or empty.
2. Unicor increases C factor to a maximum, reduces power costs, filter replacements and scraping operations.
3. Unicor costs about \$0.001 (one-tenth of a cent!) per barrel of product. One molecule of Unicor to one million molecules of product gives effective anti-corrosive action.

Stop corrosion and fouling. Save money and improve product quality. Specify UNICOR for any internal pipeline corrosion problems. If you'd like to evaluate UNICOR before you send an order, write for information and samples.

UNICOR[®]

One of the family of superior UOP additives and inhibitors available to the petroleum industry



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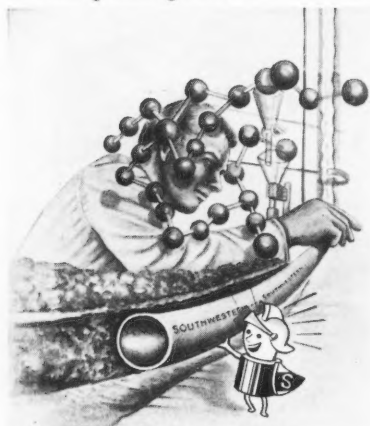
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ENGINEERED
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on your job...



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A fully-equipped laboratory; rigid quality control; constant experimentation in new types & broader uses of plastic pipe.

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A half century in the manufacture of pipe. Organized by the founders of Texas Vitrified Pipe Co. and the Cannelton (Indiana) Sewer Pipe Co., Southwestern is a pioneer in the plastic pipe field.

Complete Product Line



All standard sizes in our five lines: SOUTHWESTERN Kralastic, PVC, Polyethylene, Butyrate, Chem-Weld Drainage Pipe, and tailored dimensions in all lines to meet specific needs.

Field Supply Stocks

For prompt and complete service to you. These stocks are strategically located in the West, Southwest and South.

Engineers on Call



A trained staff of APPLICATION ENGINEERS is on call to consult with you in your pipe needs.

Call, write, or wire for information and prices

"Use Southwestern... to be sure"

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SWP-1

GENERAL BUSINESS MEETING IS MARCH 19

The annual General Business meeting of the National Association of Corrosion Engineers will be held beginning at 11 a.m., Wednesday, March 19 in Larkin Hall, San Francisco Civic Auditorium. A. B. Campbell, Executive Secretary urges everyone to attend because this meeting is the only general business meeting during the year by the association.

The agenda includes ratification by the membership of the actions of the NACE board of directors, reports of the association's officers, standing and special committees and other items essential to the association's operation.

Metallizing Talk Given To San Diego Section

About 45 attended the January 22 San Diego Section dinner meeting at Lawtons Restaurant, La Mesa. Manley H. Clark of Clark Protective Coatings, Costa Mesa presented a paper and spoke on "The Use of Metallizing as a Protective Coating for Severe Corrosive Service."

The following new officers were installed: Loy L. Flor, El Cajon, chairman; Kenneth R. Christy, Federal Housing Adm., San Diego, vice-chairman; Reuben C. Tullis, San Diego, secretary-treasurer.

Next meeting of the section will be held March 12.

Registrants From Five States at Houston Course

Registrants from five states attended the January 23-24 Houston Section Short Course for Pipeliners at the University of Houston. Paid registration totaled 86, according to W. P. Noser, Humble Pipe Line Co., course vice chairman.

Instructors were C. L. Woody, United Gas Corp.; M. A. Riodran, Rio Engineering Co.; E. R. Allen, Humble Pipe Line Co.; C. C. Nathan, The Texas Company; Ray Tuggle, Texas Pipe Line Co.; Joseph E. Rench, Napko Corp.; Frank Wilson, Clemtex, Inc.; Pearce Butterfield, Transcontinental Gas Pipe Line Corp.

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Backfill for Anodes

Ideally suited for use with anodes. Has a high carbon content and comes in sizes of 1/2-inch x 0 to 3/4 x 1/2 inch. In bulk or sacks. Prices on other sizes on request.

National Carbon Anodes

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North Texas Section Hears About Method To Catalog Coatings

A concise and practical method of cataloging protective coatings was described by Kenneth Tator, Tator Associates, Corapolis, Pa. at a meeting of North Texas Section February 3. Mr. Tator's remarks, under the caption "Classification and Correlation of Protective Coatings," were heard by 22 members and eight guests.

Merle Frank, Gulf Engineering Co., Houston and five men from Morton Salt Company, Grand Saline, were among the guests.

Ed. Muehlhaue gave a report on the Dallas Combined Technical Societies' scientific and educational group. Gordon Meek, Metal Goods Corp. spoke on the NACE corporate membership drive now under way.

About 60 attended the first regular meeting in Fort Worth, January 6. Guest speaker Norman Hackerman, University of Texas spoke on "Basic Research and Corrosion."

A past chairman's certificate was awarded to Mr. Ed. Muehlhaue and officers for 1958 were announced as follows: Glyn Beesley, Dallas Power and Light Co., chairman; E. J. Simmons, Sun Oil Co., vice-chairman; Donald J. Taylor, Jr., Otis Engineering Corp., secretary-treasurer.

San Francisco Section Has 57 at Dinner Meeting

San Francisco Bay Area Section met January 29 for a regular dinner meeting at Spenger's Fish Grotto in Berkeley, Cal., with approximately 57 people attending. One of the section's newest members, E. F. Duffek of Stanford Research Institute, Menlo Park spoke on "Electro-Chemical Aspects of Corrosion Measurements." Aaron Wachter, Shell Development Co., Emeryville, a past president of NACE was present.

New officers were introduced as follows: J. B. Dotson, Rockwell Manufacturing Co., chairman; J. P. Fraser, Shell Development, Emeryville, vice-chairman; B. A. Kronmiller, Flox Company, Inc., Alameda, secretary-treasurer.

Riordan Talks at Longview On Cathodic Protection

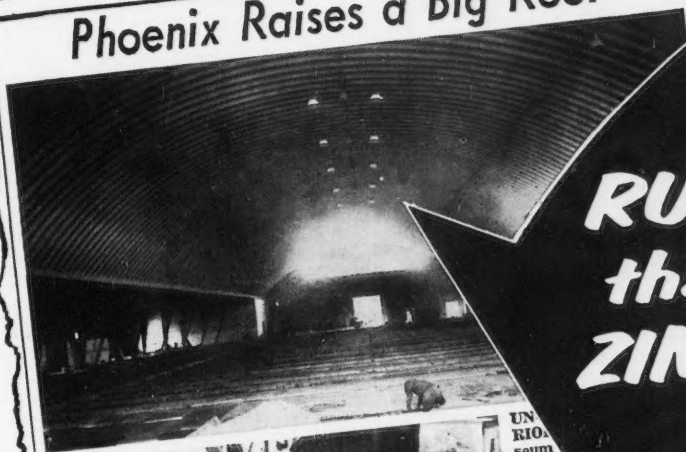
Maurice A. Riordan, Rio Engineering Company, Houston was guest speaker at the regular monthly meeting of East Texas Section January 28 in Longview. Approximately 44 people heard Mr. Riordan speak on "Fundamental Principles of Cathodic Protection." The appointment of the following members to the program committee was announced: L. W. Riall, United Gas, chairman; L. Rutherford, Magna of Texas; J. P. Hammett, Sinclair Oil & Gas Co.

Panhandle Charter Issued

As of January 30 the Panhandle Section of the South Central Region has complied with all the provisions for becoming a fully recognized section and has been issued a charter.

NEW YORK WORLD-TELEGRAM AND SUN, THURSDAY, AUGUST 9, 1956

Phoenix Raises a Big Roof



Also
RUSTLESS
thanks to
ZINC!

Trussless Steel Giant

The erection of the world's largest trussless steel roof, a clear span 120 feet wide and 260 feet long, over the new \$750,000 Phoenix Coliseum under construction in Phoenix, Ariz., was announced today by the Wonder Building Corp. of America.

Called the "Wonder Roof," it is the first in a new line of low-cost, long-span custom-engineered roof decks being marketed by the firm for convention halls, arenas, etc. Costs are said to be one-third less than conventional roof structures.

At the Phoenix Coliseum, the unique roof was completely erected in seven and one-half days.

CURVED SHEETS of corrugated steel are fastened together by nuts and bolts to form the self-supporting arches which make up the new trussless steel roof. Workmen above assemble pre-engineered sections.

Reprinted by permission of the New York World-Telegram & Sun

Two design features of the roof* of the new Coliseum in Phoenix, Arizona are somewhat unique.

1... the roof is TRUSSLESS, thanks to the use of specially designed curved steel sheets, so assembled as to form a strong, self-supporting arch.

2... the roof is RUSTLESS, thanks to ZINC.

Yes, the roof is galvanized and by the continuous galvanizing process, too, which produces a much better coating... a coating that adheres more strongly to the steel and which permits severe forming operations without damage. With this coating the metal appears to 'flow' with the base metal when being shaped.

BUT... and this is where St. Joe Electrothermic Zinc enters the picture... continuous galvanizing calls for zinc with specially controlled analyses of the other metals. It isn't a question of staying within permissible maximums. It's a question of keeping the other metals within certain specified ranges in order to impart certain desirable characteristics to the zinc and the coating.

St. Joe Electrothermic Zinc is this carefully controlled zinc. It's ideal for continuous galvanizing.

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Turn to Page 86 this issue for names and addresses of firms doing corrosion engineering work on all kinds of problems. This list appears in every issue.

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TECHE SECTION OFFICERS were installed January 10 at a dinner-dance attended by 19 couples. Officers are, left to right, Max I. Suchanek, Dowell Inc., chairman; Sam E. Fairchild, Texas Pipe Line Co., vice-chairman; John D. Stone, Sunray Mid-Continent Oil Co., secretary; O. L. Basham, Tretolite Co., trustee. Lee R. DeRouen, vice-chairman, was absent when the photograph was taken.

Teche Section Plans Nine 1958 Meetings

Next meeting of Teche Section will be Thursday, March 27 at the Petroleum Club, Lafayette, La. The club has scheduled 9 meetings during the remainder of the year, including a banquet on Thursday, June 5 during the section's second annual corrosion control course. Officers were installed January 10 at a dinner-dance.

The schedule of meetings, all at the Petroleum Club, Lafayette is: April 24, May 22, June 5, July 31, August 28, September 25, November 20 and December 18.

John D. Stone, Sunray Mid-Continent Oil Co. is director of the 1958 corrosion control short course which will be held June 4-6 at Southwestern Louisiana Institute, Lafayette.

Hill Talks at Odessa On Oil Field Corrosion

Permian Basin Section met January 14 in Odessa for a dinner meeting at which approximately 55 people were present. Preston W. Hill, Signal Oil and Gas Co., Long Beach, Cal., spoke on Corrosion in the Oil Field. The need to recognize corrosion, procedures for evaluating the economic severity of corrosion, corrosion control methods and salesmanship aspects of the corrosion engineer's job, were highlights of Mr. Hill's talk.

Corpus Christi Section Elects 1958 Officers

New officers for Corpus Christi Section for 1958 are as follows: Kenneth R. Sims, Gas Division, Department of Public Utilities, chairman; William Taylor, Gas Department, City of Corpus Christi, vice-chairman; Joseph L. Willing, Jr., Humble Pipe Line Company, secretary-treasurer; and John P. Westerveldt, Pontiac Pipe Line & Export Company, trustee.

Environment Treatment Is Topic at Chicago

Chicago Section held its regular meeting January 21 at the Chicago Engineers Club with approximately 43 present. Davis B. Boies, National Aluminate Corporation spoke on, "The Prevention of Corrosion Through Treatment of the Environment."

H. W. Howard, Shell Chemical Corporation is the next scheduled speaker on "Properties and Uses of Epoxy Resins."

Manly Talks at Houston

W. D. Manly, Oak Ridge National Laboratory spoke to Houston Section February 11 on "Fundamentals of Liquid Metal Corrosion." W. B. Brooks, Dow Chemical Co., Freeport is the scheduled speaker March 11.

South Central Region NACE meets in New Orleans in 1958.

Northeast Region NACE meets in Boston in 1958.

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GENERAL NEWS

Technical Information Center to Be Set Up

A Foreign Technical Information Center will be established in the Department of Commerce to act as a clearing house on all foreign, technological, scientific, and engineering information and make it available to American scientists, research institutions and the public. It will collect, evaluate and distribute foreign scientific and technical literature.

Arrangements have been made to collect from such organizations as the National Science Foundation, Atomic Energy Commission, the armed services and intelligence agencies and other agencies copies of abstracts and translations of foreign technical articles and books. An estimated 50,000 abstracts and 10,000 translations will be accumulated annually. Plans call for publication and release of abstracts to the technical press and that copies of translations will be made available to the public.

Special Libraries Association operates a translation center at Crerar Library in Chicago. This is supported in part by the National Science Foundation and National Institute of Health. In January, 1957 it took over the accumulated translations of the Scientific Translation Center of the Library of Congress. Scientific translations only are available from this source.

Bubble Formation May Signal Fatigue Cracking

Formation of bubbles under transparent sensitive tape fastened to surface of torsion fatigue specimens may be a means of detecting the onset of fatigue cracking. This method was developed at the National Bureau of Standards in connection with fatigue tests.

Since the bubbles formed are sufficiently large to be seen with the naked eye while the cracks are still microscopic, the discovery may be an aid in the study of crack propagation. Some metals will not produce the bubbles and they are produced at different rates in different metals. Experimenters believe the bubbles indicate the phenomenon is due to surface reactions.

U.S. Research Laboratories Now Number About 3800

The number of research laboratories in eleven large industries in the United States has increased from 1800 in 1945 to nearly 3800 in 1955, according to Galaxy, Inc. in a study made for the National Science Foundation. Scientists employed rose from approximately 50,000 to about 120,000. Researchers estimated organized research in the United States represents an annual \$7 billions business.

• Northeast Region NACE meets in Boston in 1958.

• CORROSION's 10-year alphabetical subject index covers the years 1945-54.

BOOK NEWS

The Making, Shaping and Treating of Steel. 1048 pages, (Seventh Edition) 8 x 10 5/8 inches, cloth. April, 1957. United States Steel Corp., Office Service-Stores, 525 Wm Penn Place, Pittsburgh 30, Pa. Per Copy, \$7.50. Students, \$5.

This edition of the U. S. Steel Corp. compendium on steel has been revised extensively and expanded. The material on corrosion especially has been regrouped and a large part of the basic information on steel corrosion has been collected in one chapter. Indexing of corrosion references elsewhere is adequate.

An extensive discussion of the theory of corrosion, in Chapter 35 is followed by sections on protective coatings, surface preparation, conversion coatings, chemical treatment and other related information. Indexed references also are made to corrosion-connected material published in sections devoted to alloy steel, testing heat treatment, fatigue and other factors.

The index, from A (1) to Zirconium is one of the best features of the book.

Engineering Materials Handbook. Charles L. Mantell, Editor. 1936 pages, 6 x 9 inches, flexible cloth. January, 1958. McGraw-Hill Book Company, 327 W. 41st St., New York 36, N. Y. Per copy, \$21.50.

In 43 sections devoted to metals, organic and inorganic materials and the cause and prevention of failure of materials, this book gives a comprehensive picture of the whole engineering materials field. Data covered include design information, structural characteristics, physical and mechanical properties, adaptations, advantages, limitations, competition with each other, protection against deterioration and others.

An 83-page alphabetical subject index enhances the value of the book. There are 35 references to corrosion. These relate principally to Section 37, Corrosion and Protection Against Corrosion prepared by T. P. May, The International Nickel Co., Inc., one of 150 contributors to the book. This section considers the theoretical aspects of corrosion, covers testing extensively and examines the various factors that influence the corrosion rate of metals. Also covered are some aspects of inhibition by chemicals, concentration cells, and physical factors influencing corrosion, such as surface condition and stress.

Some attention is given also to protective coatings, and the influence of design. Theoretical and practical aspects of cathodic protection are covered in some detail.

In the next section, 38, Materials of Construction for the Process industries, 18 pages of graphed data are given on the corrosion resistance of materials to common process chemicals. These tables rate both metals and non-metallic materials. In Chapter 40, Gaskets, Packing and Seals, five pages of tabulated data

are given on the resistance of gasket materials to corrosives. In Chapter 42, Materials Problems in the Petroleum Industry, considerable attention is paid to corrosion reactions of materials.

The volume of information in this book on corrosion and its prevention is extensive.

Methods for Emission Spectrochemical Analysis. 488 pages, 6 x 9 inches, cloth. October, 1957. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. Per Copy, \$7.

This book, sponsored by ASTM Committee E-2 on Emission Spectroscopy collects under one cover much of the reliable information on this method of analysis, which grows rapidly in popularity as the need to identify very small quantities of materials becomes more pressing. Workers in corrosion, especially those concerned with analysis of corrosion products, often find spectrochemical analysis useful.

Committee E-2, which has been engaged in a program leading to standardization of spectrochemical practices since 1932, points out that in the present state of knowledge about this specialty much of the data and procedures are not specifically adopted. The book is divided into four major sections, general practices, nomenclature, spectrochemical analysis of metals and spectrochemical analysis of non-metals. As usual in ASTM publications, the data are complete, concise and authoritative.

Aluminium von Innen Betrachtet. By Dietrich Altenpohl. (Aluminum for Your Consideration) (In German) 200 pages, 5 1/2 x 8 inches, paper. Aluminium Verlag GmbH, Jagerhofstrasse 26/29, Dusseldorf 10, Germany. Availability not indicated.

A comprehensive discussion of the refining, forming, tempering and fabrication of aluminum. Considerable data, with related illustrations are given regarding grain characteristics, crystallographic information, atomic arrangements and other matters. Photomicrographs are used liberally.

Diagrams, graphs and photographs are used extensively throughout the book to illustrate subject matter.

An interesting feature of this book is a dictionary of terms used in the aluminum industry. There is an alphabetical subject index.

Boron, Calcium, Columbium, and Birconium in Iron and Steel. Frank T. Sisco, Editor. 1957. 533 pages, 5 3/4 x 8 7/8 inches. John Wiley & Sons, 440 Fourth Ave., New York 16, N. Y. Per copy, \$14.

This is the fourth volume of the new monograph series "Alloys of Iron Research" a publication project of the Engineering Foundation, New York. It correlates and summarizes data from hundreds of sources on the effects of the named metals as alloying elements in iron and steel. The accumulated information is valuable to corrosion workers concerned with high-temperature and

(Continued on Page 86)

How You Can Get Copies Of Conference Papers

Technical papers presented during the 14th Annual Conference at San Francisco will be published in **CORROSION** as approved by the editors beginning with the April issue. Members of the National Association of Corrosion Engineers will, therefore, ultimately receive copies of all papers approved for publication. Because they are included in **CORROSION** and are indexed topically and otherwise, the necessity of maintaining separate files and indexes is eliminated.

- Subscribers to **CORROSION** also enjoy this same access to NACE technical material.

In addition to conference papers **CORROSION** also publishes technical material originating at regional and sectional meetings and sent to NACE by authors seeking an effective medium for presentation of their work.

NO COPIES OF CONFERENCE PAPERS ARE AVAILABLE FROM CENTRAL OFFICE NACE.

BOOK NEWS PERIODICALS

(Continued From Page 85)

high pressure applications of materials, especially in the rapidly expanding atomic and missile fields.

Authors R. A. Grange, F. J. Short-sleeve, W. O. Binder, D. C. Hilty, and C. M. Offenbauer are known to corrosion workers directly or by reference. Numerous other experts contributed information and other services to complete the work.

The book considers the materials effect on iron and steel in the order named in the title. Effect on structures, machining properties, heat treatment and other properties are reviewed. There is an alphabetical subject index and an alphabetical author index.

ACE Day is May 2

The Fifth Annual Conference for Engineers and Architects, sponsored by the Ohio State University College of Engineering will be held May 2 on the campus of Ohio State University, Columbus. Among the technical sessions to be presented is one in the field of nuclear engineering which will cover, among other topics "Non-Destructive Testing of Nuclear Components."

Report of Association of Large Boiler Owners. (In German) 8½ x 11 5/8 inches, Vol. 45. Published bi-monthly by Vereinigung der Grosskesselbesitzer E.V., Kurfürstenstrasse 27, Eesen 1, den, Germany.

The December 1956 issue contains 97 pages of technical information and 38 pages of advertising and other material. Much of the technical information in this issue is either about corrosion control or on related subjects.

Influence of Wet Ground Mica on Coatings Given

"Studies on the Influence of Wet Ground Mica on the Water Vapor Permeability of Paint Films," Technical Bulletin No. 34 of the Wet Ground Mica Association, 420 Lexington Ave., New York 17, N. Y. describes test methods and influence of mica under the conditions tested. Max Kronstein, New York University, has charge of the research program underway by the association.

CORROSION's Technical Section published 190 more pages in 1957 than in 1956.

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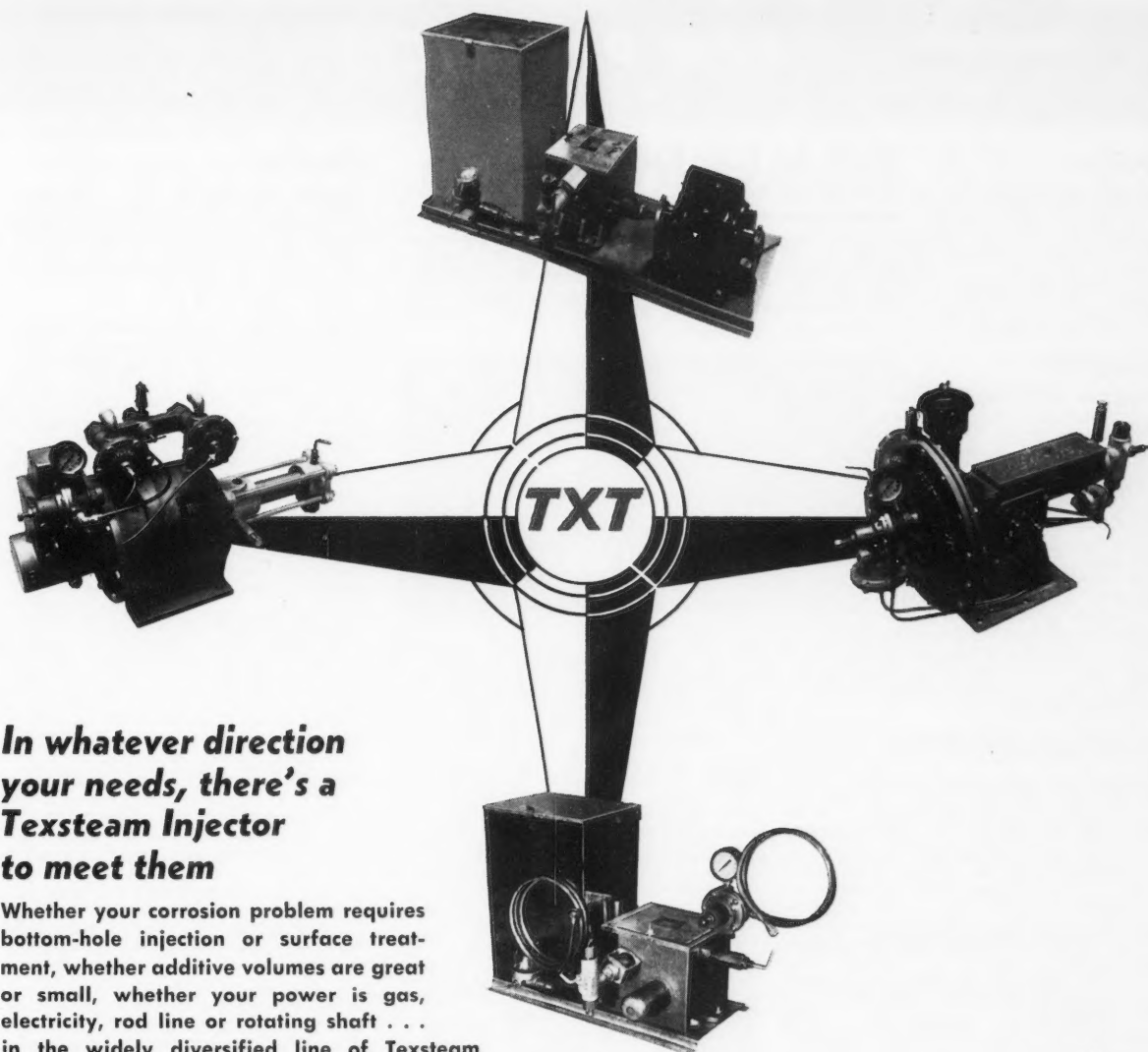
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- SERIES MSM-5001 (right) Volumes to 700 gallons per day; injection pressures to 20,000 psi; air or gas operated. Four sizes.
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NEW PRODUCTS

Materials Literature

Boilers

Carbon Monoxide will be used as fuel for a 200 million BTU boiler being erected at the new Standard Oil Co. (Ohio) Toledo refinery by Babcock & Wilcox Company. It is designed to produce 450,000 pounds of steam hourly, believed to be the greatest capacity of any carbon dioxide boiler so far constructed.

Ceramics

Impervo Brick and Tile made by Hanley Company, One Gateway Center, Pittsburgh 22, Pa., are described in a new catalog "Hanley Industrial Products."

Coatings—Metallic

Sylvania Electric Products, Inc., 1740 Broadway, New York 19, N. Y. has developed a process for electroplating copper on aluminum strip and wire. It is possible to plate aluminum strip up to 10 inches wide and in thicknesses from 0.008 to 0.050-inch with copper in thicknesses from flash coatings to 0.002-inch per side. The plated materials can be tinned, soldered or formed without breaking the plating.

Coatings—Organic

Butyrate Lacquer has been used to coat aluminum exteriors of a building erected for American Sterilizer Company, Erie, Pa. The decision to coat the aluminum followed weathering and corrosion by industrial fumes of siding in an older part of the building when compared to a newly-constructed part. The butyrate coating was tested nine months on surfaces close to foundry exhausts before a decision to use it was reached. The coating, Pyroxcote 26-105 was supplied by Pyroxylin Products, Inc., Chicago. The half-second component of the lacquer was developed by Eastman Chemical Products, Inc., 260 Madison Ave., New York 16, N. Y. The surface was passivated after cleaning with Aodine No. 1000.

Equipment—Process

Graver Water Conditioning Co. has become a completely integrated and wholly-owned division of Union Tank Car Company, Chicago, which recently acquired the assets of Graver Tank and Mfg. Co., Inc., East Chicago, Ind.

Niagara Welding and Boilers Works, Inc., 811 Linwood Ave., Niagara Falls, N.Y. describes in a folder its facilities, services and qualifications for making equipment for the chemical, food beverage, power, heating and other industries.

Dean Thermo-Panel Coil Div., Dean Products, Inc., 616 Franklin St., Brooklyn 38, N. Y. describes in Bulletin 258 the sizes and materials of its thermal panels.

Fittings

Hose Nipples of 316 stainless steel are available in sizes from 1/4-inch to 1x1-inch from the Band-It Co., 4777 Dahlia St., Denver 16, Col.

Fume Control

Sersal chemical blankets on hot phosphate coating baths act as barrier to prevent escape of steam and fumes and save up to 70 percent of heat. American Chemical Paint Co., Ambler, Pa., which developed the blanket, claims it eliminates the need for costly ventilating systems.

Heil Process Equipment Corp., 12901 Elmwood Ave., Cleveland 11, Ohio describes in Bulletin B-71 its solid plastic, reinforced plastic, rubber and plastic lined steel, stainless steel, alloys and lead fume scrubbers. Wet cyclone, packed tower and special types are available.

Instruments

Fisher Research Laboratory, 1961 University Ave., Palo Alto, Cal. is producing a transistorized M-scope for location of pipe and leaks underground. Newly designed components, including transistors, make the device extremely sturdy and give up to 1500 hours' operation on batteries. The new unit weighs 12 pounds.

Goldak Company, 1544 West Glenoaks Blvd., Glendale 1, Cal. is offering a rugged transistorized pipe locator, with encapsulated components to reduce damage from accidental shocks and vibrations. The unit uses four Size C flashlight cells for power.

Insulators

F. H. Maloney Co., Box 1777, Houston 1, Texas has developed a new plastic pipe line insulator for use on cathodically protected systems. The new Model 57 insulator is available in sizes from 2 through 36 inches. Made of compressed glass fiber and polyester resins it is ribbed inside to prevent cold flow of pipe wrap.

Metals—Ferrous

Wrought Iron electrical conduit made by National Electric Products Corp., Room 900, 2 Gateway Center, Pittsburgh, Pa. describes its Sherardized conduit in an illustrated 8-page brochure. The conduit, after pickling and galvanizing is coated inside and out with vinyl enamel. Both threads and couplings are galvanized.

Pipe

Epoxy-Bonded 30-degree elbows have been added to the J-M line of Transite building sewer pipe manufactured by Johns-Manville Co. The new elbow incorporates the Ring-tite system in which two integral rubber rings are compressed between the pipe wall and the coupling or fitting.

Plastics

Type-S Fluorflex-T pipe and fittings and molded Teflon bellows are described in two bulletins available from Resistoflex Corp., Vineland, N. J. The materials are said to be chemically inert at temperature up to 500 F.

Light Weight injection molded unplasticized polyvinyl chloride pipe fittings now being produced by Tube Turns Plastics, Inc., Louisville 1, Ky. are designed for use in systems with moderate pressure and temperature conditions. The new fittings will match the bursting strength of Schedule 40 PVC pipe and cost one-third less than the company's regular line of heavy wall fittings. Made in both normal and high-impact formulations, they are available in 90 and 45-degree elbows, tees, couplings and caps in 3/4 to 2-inch sizes as well as 3 and 4-inch couplings.

The Role of Polyethylene in Creative Packaging and Successful Selling, a booklet available from Dept. 1141, Bakelite Co., 420 Lexington Ave., New York 17, N. Y. describes the ways in which polyethylene is being used in packaging.

Teflon chemical and mechanical seals produced by Tri-Point Plastics, Inc. 175 I. U. Willets Rd., Albertson, L. I., New York are designed for uses involving corrosive or high pressure and temperature chemical processes. O and V rings with square, round and oval cross sections are being made to a maximum OD of 15/16-inch, 3/4-inch ID. When necessary tolerances can be held to 0.001-inch.

Rigid Polyvinyl Chloride plastic is available in bar stock from 3/4-inch rounds to 2-inch and in 10-foot lengths. The stock is sold under the trade name Ryertex-Omicron PVC by Joseph T. Ryerson & Son, Inc., Box 8000-A, Chicago 80, Ill.

Propellers

A 21-foot, five-bladed Nialite propeller was found to need no reconditioning after three years' service on a California Transport Corporation oil tanker. The standard manganese bronze propeller on ships of this type usually requires reconditioning after three years because of corrosion and cavitation damage. Maintenance of original profile during a long service life is expected to make substantial savings in fuel consumption over the life of the wheel. It was made by Baldwin-Lima-Hamilton Corp., Philadelphia 7, Pa.

Pumps

Model HCT "Minilab" low capacity rotary pumps are made by Eco Engineering Co., 12 New York Ave., Newark 1, N. J. with Hastelloy C bodies and Carbon or Teflon impellers, bearings and Teflon packing.

(Continued on Page 90)

Draley Is Chairman Of Gordon Corrosion Conference July 14-18

Joseph E. Draley, Argonne National Laboratory, Lemont, Ill., and P. M. Aziz, Aluminum Laboratories, Ltd., Kingston, Ont., will be chairman and vice-chairman of the corrosion conference, one of the Gordon Research Conferences to be held July 14-18 at Colby Junior College, New London, N. H.

The scheduled technical program is as follows:

Nature of Metal Surfaces: H. Juretschke, "Atomic Nature of Metal Surfaces;" C. S. Smith, "Metallography and Corrosion."

Adsorption on Metals: J. T. Law, "Adsorption Process on Semiconductors;" L. S. Bartell, "Optical Studies of Adsorption from Solution;" R. T. Gomer, "Field and Ion Emission Microscopy;" P. W. Selwood, "Magnetization and Surface Chemistry."

Oxides on Metals: J. V. Cathcart, "Microphotography of Oxide Films on Metals;" Jerome Kruger, "Growth of Oxide Films on Copper in Water Containing Oxygen;" W. D. Feitknecht, "Chemistry of the Corrosion Products Formed on Cu, Cd, Zr and Fe in Aqueous Solutions;" E. A. Gulbransen, "Crystal Habits in Localized Corrosion and Oxidation Processes in Relation to Metal Structure."

Passivity: Review of Darmstadt Passivity Colloquium and general discussion on passivity mechanisms.

Others of the Gordon Research Conferences will be held from 9 June to 29 August at Colby Junior College, New London; New Hampton School, New Hampton and Kimball Union Academy, Meriden, N. H. The conferences are designed to give scientists in related fields an opportunity to consider progress in their fields and informally discuss their interests with others of like interest. No publications emanate from the conferences and no information divulged may be used without permission.

Electrochemical Society To Hear Over 150 Papers

Over 150 papers will be presented April 27-May 2 at Hotel Statler, N. Y. by The Electrochemical Society. Five Divisions scheduling technical sessions are: Electric insulation, electronics, electrothermics and metallurgy, industrial electrolytic and theoretical electrochemical.

A symposium on stress corrosion cracking of stainless steels will be given in addition to others on high purity metals, semiconductor materials, fused salt electrolysis, ceramics, plastic insulation, printed circuits and electrokinetic phenomena.

Abner Brenner, National Bureau of Standards, will give the Richards Memorial Lecture on "Electrolysis in Non-aqueous Solutions."

Northeast Region NACE meets in Boston in 1958.

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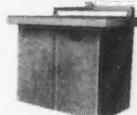
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NEW PRODUCTS

(Continued From Page 88)

Rectifiers

Cathodic Protection rectifiers made with selenium, germanium or silicon packs are available from Rapid Electric Co., 2881 Middletown Road, New York 61, N. Y. Single and three-phase models in a wide range of voltages and amperages are made in waterproof outdoor-type enclosures.

Seals and Gaskets

Rotary Seal Division, Muskegon Piston Ring Co., Sparta, Mich. has issued a booklet "solving the problem of seals

for rotating shafts," which considers design problems in detail. Operations of the company are described and illustrated.

Valves

Fluidmaster Model 400 anti-siphon ball-cocks made by Fluidmaster, Inc., 132 East Orangethorpe Way, Anaheim, Cal. for use in toilets are made of 200 and 300 series stainless steels, for resistance to corrosion and trouble-free operation. Tested at pressures from 0 to over 250 psi, the new valve has a concentric float made of linear polyethylene; the hush tube is made of polyvinyl chloride and the refill tube of Neoprene. The new design requires a maximum of four ounces for shut-off, while conventional compound leverage cocks need about 14 pounds.



E. R. P. engineers use modern methods to get design data for a pipeline cathodic protection system. This group is making current requirement tests for designing a ground bed.

E. R. P. DESIGNS CATHODIC SYSTEMS That Give Maximum Pipeline Protection

E. R. P. corrosion engineers are trained specifically in cathodic protection techniques. They evaluate all pertinent data *before* designing a pipeline cathodic system. *After* design and installation, continued E. R. P. surveys help maintain the efficiency of the system. They warn of environmental changes that affect complete protection.

Cathodic protection is, after all, like any tool. It requires skill and knowledge to use the tool successfully.

The cost of a cathodic system should always be measured by the savings achieved through maintaining full corrosion control, not just by the first cost of the system. On this basis E. R. P. designed cathodic systems give maximum savings for each dollar spent. For full information about E. R. P. cathodic protection for pipelines write for Bulletin E-43.



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MEN in the NEWS

Eugene Herzog has been made director of the research center of Pompey Steel-works, Paris, France.

C. Kenneth Eilerts, NACE member and co-author of a section of the report of Technical Practices Committee 1 on Corrosion of Oil and Gas Well Equipment in July, 1950, has been given the Distinguished Service Award and Gold Medal of the Department of the Interior. He is a physical chemist and petroleum engineer of the Petroleum Experiment Station of the Bureau of Mines, Bartlesville, Okla. Eilerts, in the technical service of the government for more than 27 years, has gained an international reputation for his work on petroleum and more recently for his work on phase relations in gas condensate fluids. The NACE report concerned field testing of 32 alloys in flowstreams of condensate wells.

James D. Ghesquiere, chief engineer of The Hinchman Corp., Detroit, has been named a director and secretary of the corporation.

T. E. Veltfort, managing director of the Copper and Brass Research Association, has been elected chairman of the standards council of the American Standards Association.

Glenn W. Camblin, vice-president of Petrolite Corp. and general manager of Tretolite Company of California Division since 1930, retired January 1 after 33 years of service. He was succeeded by **Louis T. Monson**, formerly chief chemist of the division, a member of NACE.

T. D. Brissman is now manager of sales Houston district office of National Tube Division, United States Steel Corp. He first worked for National Tube in Houston in 1939.

Owen F. Shobe has been retained by Lead Industries Association as a paint engineering service consultant.

Bruce M. Gifford has been named manager of Industrial Applicators, Inc., a division of Plastic Applicators, Inc., at Baton Rouge, La.

James C. Jordan is the regional manager of the Brant & Nielsen Co., Inc. Gulf Coast operations with offices in Houston at 642 M & M Bldg.

Edward H. Winkleman has been named eastern regional sales manager of Pittsburgh Coke & Chemical Company's Industrial Chemicals Division, working out of the firm's New York City office.

G. H. Cartledge, Oak Ridge National Laboratory, Oak Ridge, Tenn. is among those who will deliver papers during the May 31-June 8 12th Chemical Engineering Exhibition and Congress at Frankfurt, Germany.

John H. Merrell, honorary director of Raybestos-Manhattan, Inc. died January 4 at Chicago.

(Continued on Page 91)

MEN in the NEWS

(Continued from Page 90)

Robert L. Kane is manager of the Dallas office of Titanium Metals Corporation of America located in the Exchange Bldg.

J. M. Fouts has been made Northeastern Division sales manager for Falcon Line Products Corp. He will work from the firm's Elizabeth, N. J. branch office. An NACE member, he has been active in technical committee work and formerly was with Koppers Company and New York Telephone Company.

Edgar L. Crowley and John R. Weinert have joined the Research and Development Department of Pittsburgh Coke & Chemical Co.

Donald A. Drake, new Southwestern district manager for Tube Turns Plastics, Inc. is in charge of the sales office located at 7714 Wedgewood Lane, Houston.

Charles D. Krieg, Tretolite Co. Division, Petrolite Corp. will carry on liaison work in the Houston area, especially on refinery problems.

Max B. Roosa has been elected executive vice-president of Parker Rust Proof Co., Detroit.

L. C. Begg will move from Buffalo, N. Y. to become director of the Ampco Metal, Inc. European Information Center at Paris, France.

Jim Orchard, Longview; **Henry Fischer**, Houston; **John Sellect**, Lafayette; **Jerry Mitchell**, Bakersfield; **Sam Burnell** and **Jim Haynes**, Great Bend and **Jim Scott**, Tom Inabnet and **Tom Carr**, all of Odessa, attended a three-day conference of field representatives of Nacor Chemical Co. at Odessa.



TECHNICAL REPORTS

on

MARINE COATINGS

T-1M Suggested Coating Specifications for Hot Application of Coal Tar Enamel for Marine Environment. A Report of NACE Technical Unit Committee T-1M on Corrosion of Oil & Gas Well Producing Equipment in Offshore Installations. Publication No. 57-8. Per Copy \$5.00.

T-1M Suggested Painting Specifications for Marine Coatings. A Report of NACE Technical Unit Committee T-1M on Corrosion of Oil & Gas Well Producing Equipment in Offshore Installations. Publication No. 57-7. Per Copy \$5.00.

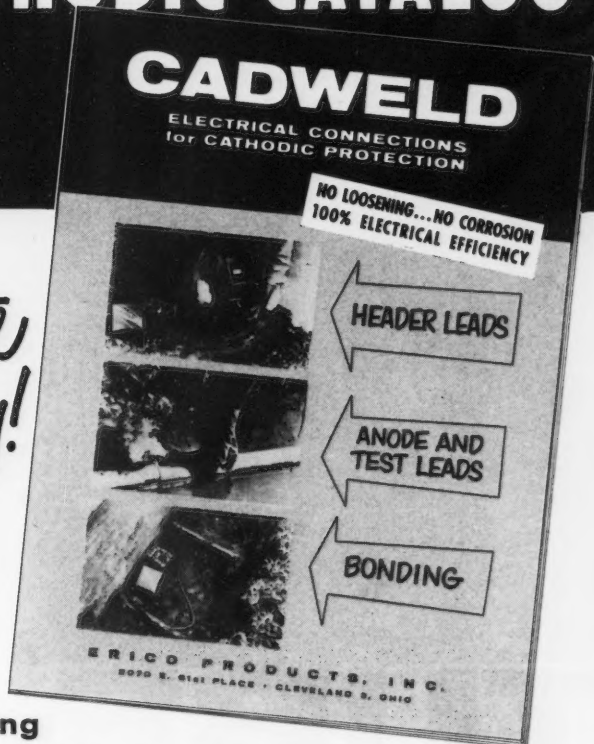
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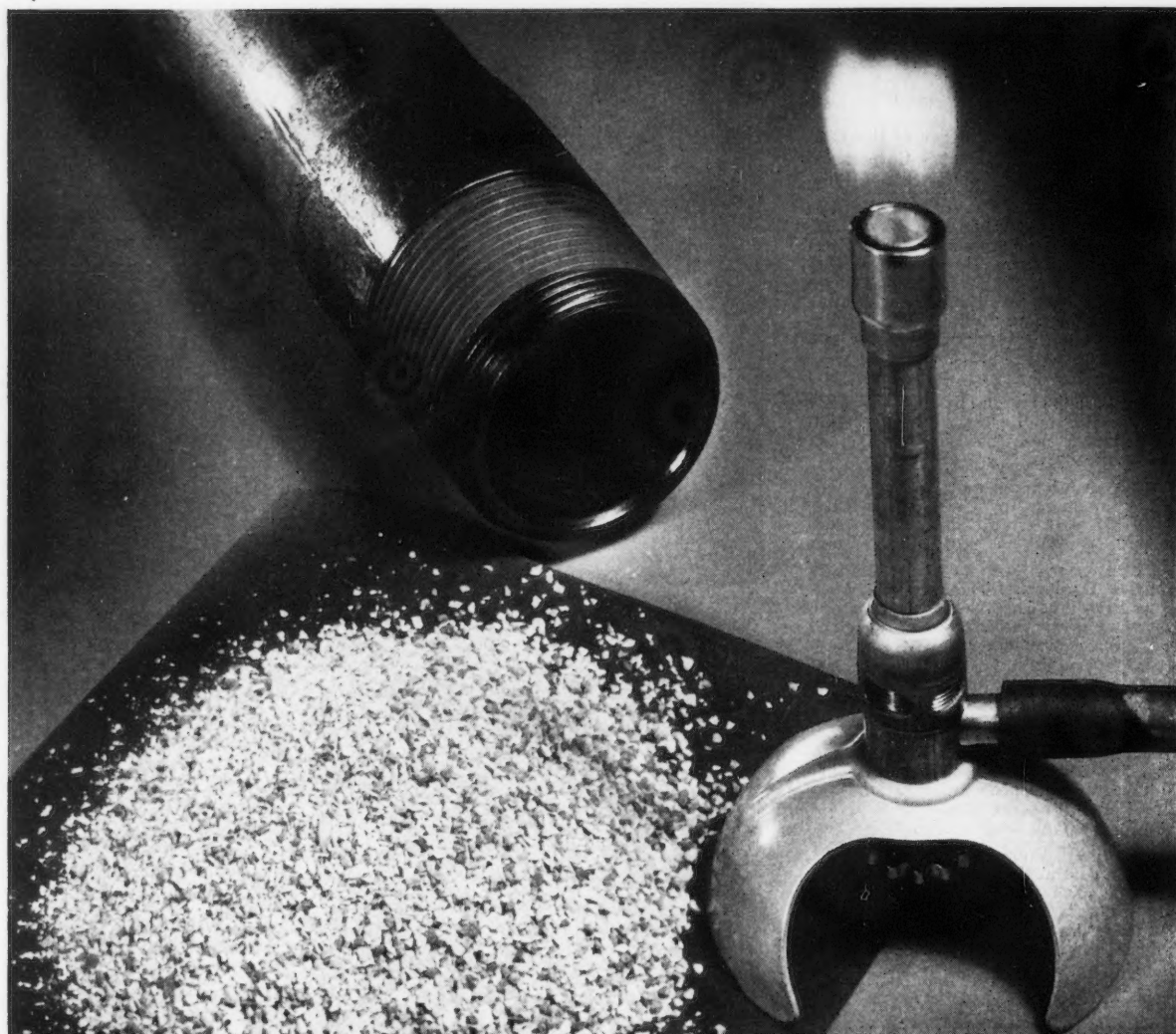
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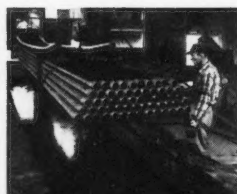
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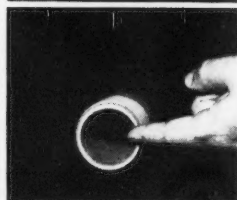
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TECHNICAL TOPICS

Performance of Epoxy Resin Coatings in Marine Environments*

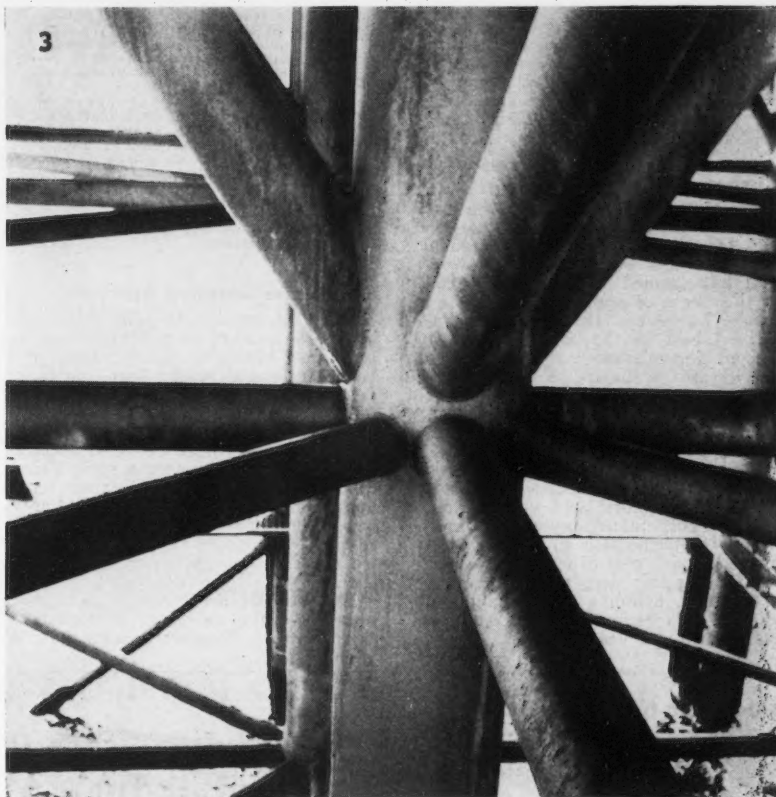
Introduction

SEVEN YEARS' service in marine environments of various types of epoxy resin coatings on structural steel, tanks, boats and the like are reviewed. Air dried or cold cured coatings known as the poxy esters, epoxy amines and epoxy polyamides only are discussed.

The high stability of the ether type linkage of the epoxy molecule make it a natural raw material for use in protective coatings for service in marine environment where resistance to water, alkali, aromatic and aliphatic hydrocarbons, a wide variety of chemicals and sunlight is desired. Aggressive research has developed a series of epoxy resin coatings equal or superior to many other coatings.

Epoxy coatings have excellent properties of cohesion and adhesion. Although surface preparation is not as critical a factor in performance as in the case of some other types of coatings,

*A paper presented by F. A. MacDougall, Shell Oil Company, New Orleans, Louisiana at a meeting of South Central Region, National Association of Corrosion Engineers, Oklahoma City, Oklahoma, October 1-4, 1957.



Class A or white metal surface sandblast is desired. Drying times compare favorably with those of other coatings although cold cured or amine types dry better at warm temperatures.

Epoxy Ester Coatings

Epoxy esters are prepared by esterifying epoxy resin with vegetable oil fatty acids, such as castor, tall, soya or linseed oils. Of these the castor oil type has proved outstanding in marine work by forming a tough and resistant film. An

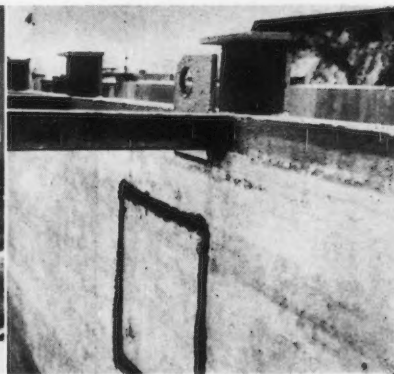
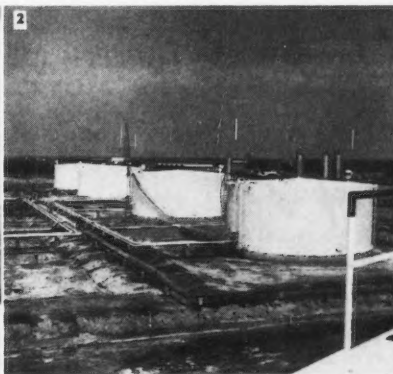
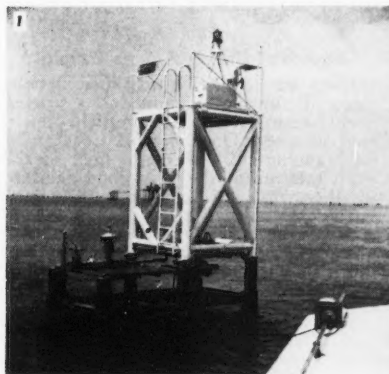
(Continued on Page 96)

Figure 1—Individual well jacket. Upper section painted with 4-coat epoxy-ester system in field. Shown after 15 months' service.

Figure 2—Large terminal located at edge of Gulf of Mexico. Four-coat epoxy-ester system is shown after 10 months' service.

Figure 3—Interior column of self-contained drilling structure. Four-coat amine cured epoxy mastic system shown after 30 months' service.

Figure 4—Interior of liquid mud tank. Four-coat amine cured epoxy mastic system shown after 18 months' service.



Performance of—

(Continued from Page 93)

early application of this type of formulation on well jackets and production equipment in the Corpus Christi Bay area in 1951 as a maintenance paint showed it to be outstanding. Its good wetting and bonding characteristics permit limiting surface preparation to hand cleaning. The epoxy ester dries well and has good color retention and chemical resistance. Satisfactory service has ranged from two to three years at a cost of 10 to 12 cents per square foot per year. It can be applied by usual oil field labor.

Atmospheric Service Best

Application should be limited to areas above the water line. Because the esters complete with amine-cured epoxy coatings for service in marine environments, their use has been limited. However, they have gained favor recently because of their ease of application and maintenance. In general the esters have performed best in the atmospheric zone. Recent formulations are giving good service also in the splash zone.

Currently they often are used in field maintenance painting in preference to ester and amine-cured systems. Figure 1 shows a well jacket after some 15 months' service following repainting in the field. The sandblasted structure received a phosphoric acid wash primer, a red zinc chromate epoxy ester primer, a coat of intermediate gray epoxy ester and one finish coat of epoxy ester white. Cost of repainting was 25 cents per square foot including material and application. It is estimated this system will last over three years.

Abstract

Performance of epoxy-resin formulations in atmospheric and submerged marine environments is reported. Formulations in incorporating esters, amine cured, polyamide cured and coal tar formulas are discussed with respect to surface preparation, primers, coating systems and application problems common to the Gulf Coast. Good service on self-contained drilling platforms for periods up to 2½ years is reported for some systems. Difficulty experienced with the several formulations in securing adhesion to freshly galvanized surfaces is reported and some partial solutions suggested.

Comparison of coating costs on three self-contained drilling platforms is given. This shows a difference of 22 cents per sq. ft. between yard costs for one platform compared to another. The final difference of 15 cents per sq. ft., the author says, resulted because of high cost of field touch-up. The author believes film thicknesses in excess of 10 mils are required for marine exposures. 5.4.5

Marine Locations Application

Large quantities of epoxy ester paint have been used to paint tanks at marine locations. Figure 2 shows tanks in a large terminal all with a four-coat epoxy ester system for a dry paint film thickness of 6 mils. After 10 months' service the coating is in excellent condition on all surfaces except at welds on decks of two tanks where numerous spots had to be repainted six months after initial application. Apparently some weld areas were not cleaned properly and minor rusting was bridged subsequently by finish coats. Failure occurred in less than six months.

The full cost of the system is unknown because of the nature of the construction contract. However, paint material

cost was approximately 7 cents a square foot. A new tank to be constructed in this area will have the top deck coated with an amine cured system for added corrosion resistance in this severe service.

Zinc Galvanizing Applications

Because standard construction practice in many companies calls for hot dipped zinc galvanized steel structures for use offshore, a satisfactory paint system using epoxy resins has been elusive. A paint system incorporating a zinc dust primer resulted in a reasonably satisfactory coating, but adhesion still is below the desired level. Service of this system has been satisfactory, however, with only minor failures after a year.

Amine Cured Epoxy Coatings

Amine-cured types are among the most widely used epoxy paints in marine environments. These two-package systems produce a hard and durable paint film with a high build per coat. They air dry in two to six hours but it takes some seven days for them to develop their full chemical resistance.

At times, depending on formulation, the film becomes so hard recoating is difficult. They have performed outstandingly on structural steel because of their ability to withstand impact and abuse. The coating is similar to one obtained by baking. Curing is by chemical reaction of ingredients when reactive portions of the epoxy resin molecule are crosslinked by action of an amine such as ethylene diamine or diethylene triamine to form insoluble, infusible materials like those normally encountered among baked phenolic and amino resins. Amine cured epoxy paints have been used on work boats, well jackets, self-contained drilling platforms, submersible drilling barges and other marine equipment.

Systems range from the thin film through the heavy mastic applications. A typical amine cured epoxy paint system includes:

1. Sandblast to white metal surface.
2. One coat red lead primer, 2 mils dry film thickness.
3. One coat red lead primer, 2 mils dry film thickness.
4. One coat gray mastic, 8 mils dry film thickness.
5. One coat enamel (yellow), 2 mils dry film thickness.

This gives a dry film thickness of over 14 mils at a material cost of some 15-16 cents.

Other systems omitting the heavy mastic result in dry paint films of 6 mils or more. They are adequate for oil field equipment and tanks exposed to marine atmospheres.

Improved Curing Agents Helpful

Early amine cured epoxy formulations using diethylene triamine as a curing agent were difficult to apply in moist, cool weather. On the Gulf Coast with its high humidity through most of the year, this meant the only good painting weather was in the summer. DTA curing agents in coatings applied produced very slow drying paint films which blushed easily. (Blushing is the term given to the white haze which develops on the surface of the coating as the result of moisture condensation.) While blushing does not detract from coating performance, it affects appearance and

(Continued on Page 96)

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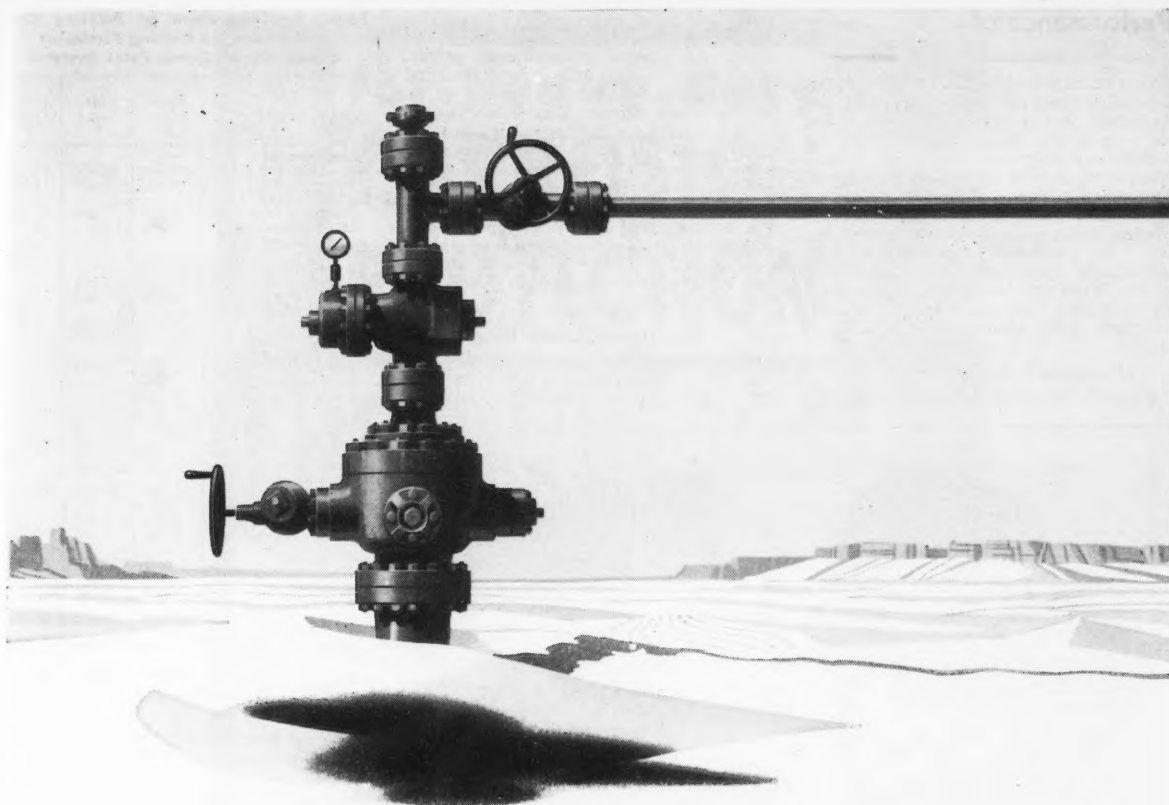
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Performance of—

(Continued from Page 94)

makes recoating difficult. In some cases, depending upon the temperature and film thickness, it has taken 24 to 36 hours for a paint film to air dry to touch.

Approximately two years ago a new proprietary curing agent was introduced. This curing agent, when incorporated into epoxy formulations, produced a coating much more resistant to blushing and with a greater tolerance for lower application temperatures and high humidity. Coatings based on formulations incorporating this agent have been satisfactory under almost all weather conditions.

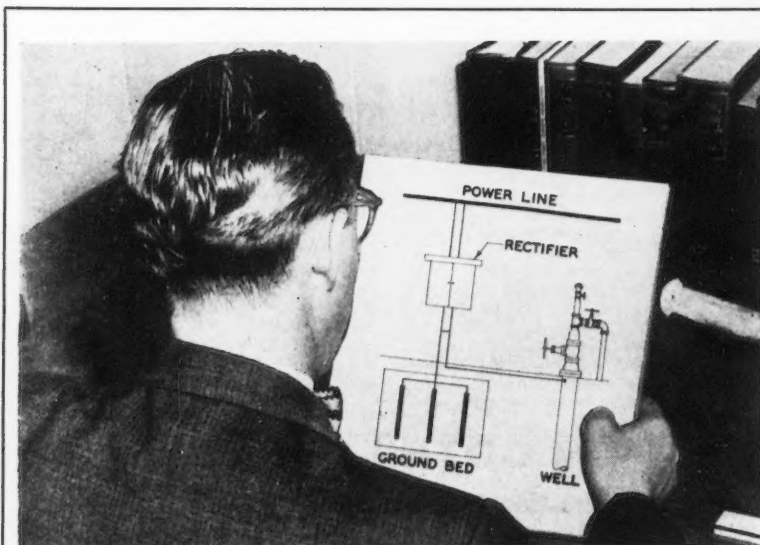
Galvanized Surface Problem

As with the esters, considerable diffi-

culty has been experienced in applying the amine cured epoxy to galvanized surfaces. At first, a conventional solvent wash and red lead primer was specified. This system failed and a special galvanizing wash primer also failed in less than five months. Following this a modification of the wash primer was tried allowing sufficient time for complete reaction. The primed surface then was neutralized with fresh water, dried and the amine cured epoxy system applied. A coating with fair adhesion resulted. Life of the system was 15 to 18 months but because of application problems it is not widely used.

Zinc-Based Primer Used

A zinc-based amine epoxy primer similar to the ester primer has been used satisfactorily. After application of this



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TABLE 1—Comparison of Painting Costs Self-Contained Drilling Platforms Amine Cured Epoxy Paint Systems

	Platform A	Platform B	Platform C
Areas Painted			
Above Monel.....	68,500	69,600	69,600
Below Monel.....	59,500	8,000	8,000
Paint (Gallons)			
Red Lead Primer...	1,120	590	590
Intermediate Gray...	295		
Mastic.....			660
Intermediate Yellow Mastic.....		1,300	
Final Yellow Mastic.....	4,235	485	
Final Yellow Enamel Thinner.....	935	1,265	545
Coverage Factors (sq. ft. gal.)			
Red Lead Primer...	229	264	264
Intermediate Gray...	232		
Mastic.....			117
Intermediate Yellow Mastic.....		60	
Final Yellow Mastic.....	30	60	
Final Yellow Enamel Thinner.....			142
Costs (per sq. ft.)			
Paint Material Cost.....	\$0.322	\$0.278	\$0.145
Labor—Yard Fabrication.....	0.229	0.180	0.180
Field Touch-Up...	0.092	0.140	0.160
Total.....	\$0.643	\$0.598	\$0.485
Film Thickness (mils.)	15	16	13
Cost per sq. ft. per mil.....	\$0.043	\$0.037	\$0.037
Service to date (years).....	2.5	1.75	1.5
Cost per sq. ft./Yr. (to date).....	\$0.257	\$0.342	\$0.323

zinc dust primer to galvanized pipe isolated blistering occurred in one case.

Examination of pipe indicated that when rough, pitted pipe is hot dip galvanized, pinholes form in the galvanized coating over deep pits because contaminants are retained in them after cleaning. An organic coating applied over these pinholes tends to seal them. If the pinhole expels gas, blisters occur on the coating.

Maintenance Is Simple

Maintenance of amine cured epoxy systems has proved simple using either ester or amine cured coatings. Because of the hardness of the amine cured film, if esters are used it is recommended that the old paint film be washed with an amine-cured epoxy solvent or else the first maintenance coat be mixed one part amine-cured epoxy solvent with six parts of ester paint to soften the old coating. This gives good bite to the old surface and improves adhesion.

Four Systems Are Compared

Table 1 gives data on four-coat amine cured epoxy mastic paint systems on three self-contained drilling structures. Paint film thicknesses ranged from 13 to 15 mils. Cost of painting ranged from 49 cents to 64 cents per square foot. It is noteworthy that while the cost of yard painting was 22 cents per square foot less for Platform A than for Platform C, the final cost after erection in the field was only 15 cents per square foot less due to the high cost of field touch-up. Continued high costs of this nature tend to limit the frequency of field touch-up and maintenance.

Marine Environment Performance

Performance of amine-cured epoxy paints has been outstanding in oil field marine environments. They have shown excellent resistance to caustic muds, hydrocarbons and water. Figure 3 shows a typical column on a self-contained

(Continued on Page 98)

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Performance of—

(Continued from Page 96)

drilling platform after 2½ years' service. The system used was:

1. Sandblast to a commercial surface finish.
2. Two coats of amine cured epoxy red lead to a dry film thickness of 4 mils.
3. One coat of amine cured gray epoxy, 2 mils.
4. One coat of amine cured epoxy mastic, minimum dry film thickness, 10 mils.

Above the water line failure has occurred at points of mechanical damage, on edges of deck beams where there was insufficient film thickness and from pinholing of the coating near the water line. Although adhesion is excellent some minor underfilm corrosion has occurred. Considering that drilling operations were conducted for over 1½ years, the paint coating is in excellent condition. Other operators report even longer service on similar installations as well as on well guards and production platforms.

Good Results in Submerged Areas

After some 15 months' service the underwater portion of the structure was examined from Gulf level to a depth of 75 feet. The structure below the water line was painted with a system similar to that given above but the gray intermediate coat was omitted. This inspection showed paint to be in excellent condition except at points of mechanical damage. From water level to a —20 feet the paint was covered with brown algae and barnacles attached to the surface but not penetrating into the coating. From a —20 feet to —50 feet, barnacles become more scattered and below 50 feet none were found. Brown algae was found to bottom. Some coral was found also.

Figure 4 shows the interior of a mud tank after 18 months' service handling caustic mud. The paint is in excellent condition although discolored. The same system was used as on the upper portion of the drilling structure, the only point of failure being at a weld which probably was improperly cleaned.

Subsequent paint systems on drilling platforms have been modified somewhat to include the mastic coat as the third or "sandwich" coat. These structures are also in excellent condition after service just short of two years. Abrasion resistance is considered excellent. Examination of a vertical piling used by boats for tying to the platform indicates that while friction of the lines has rubbed paint completely off in some places, most of the piling still has the gray mastic and red lead coats intact after 21 months.

The recommended paint system now for offshore structures is:

1. Sandblast to Class A surface.
2. Two coats of amine cured epoxy red lead primer, dry film thickness, 3 mils.
3. One coat of amine cured epoxy gray mastic, 8 mils.
4. One coat of amine cured epoxy yellow enamel, 2 mils.

A curing agent of the adduct type is included. Minimum total dry film thickness to equal 14 mils.

This system is expected to give outstanding service at a minimum cost.

It is the author's opinion, verified by field exposure experience, that for satisfactory painting in marine environments, a film thickness in excess of 10 mils is required. Use of mastic or highly pigmented coatings and the advantage of a high solid formulation such as can be achieved with the epoxies which give 8 to 10 mils with one pass of the spray gun with a 50 percent overlap is very attractive from a cost standpoint. This type of coating permits obtaining thick films with minimum labor cost.

Coal Tar Epoxy Coatings

Amine-cured epoxy formulations containing coal tars are fairly recent developments and except for a few test installations little is known of their performance in marine service.

Experience with these systems is limited to some eight months' service in the Gulf of Mexico. During this time the coating has been found very tough and resistant to abrasion which would have damaged other coatings. The main difficulties have been in application due to a non-uniformity of product and occasional lamination between coats. The coal tar epoxy coating tested exhibited marked variation in viscosity from can to can. Laminations occur if too long a time elapses between coats. If recoating takes place in less than two days, good cohesion develops but if four to five days elapse, laminations invariably occur.

Nevertheless, this coating promises to be useful in marine environments because of its ease of application, high build per coat and minimum surface preparation requirements where a commercial blast finish is sufficient. Cost of a 16-mil coating is approximately 15 cents per square foot for material.

Polyamide Cured Epoxy Coatings

Other recent entries in the epoxy coatings field are the polyamide cured coatings. These were slow in development because of the poor nature of the early amides. However, with the advent of more and better polyamides, epoxy coatings using them have been developed which are hard, durable and flexible. They have good resistance to acids, alkalis, solvents and other hydrocarbons. The amides are good surface wetting agents and they can be applied on moist and damp surfaces.

A number of steel well head structures painted with the polyamide are in good condition after 21 months' service. They have been used also on drilling tenders, oyster dredges and sled barges. Performance is considered excellent where abrasion is a problem. Because of their tolerance for water, these coatings will may be the best all-around coating for use offshore, although this has to be confirmed by further exposure experience. The polyamide epoxy can be applied to an 11-mil thickness in three coats at a cost of approximately 35 cents per square foot.



TECHNICAL REPORTS

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T-6A Vinylidene Chloride Resins. A Report of Unit Committee T-6A Prepared by Task Group T-6A-3 on Vinylidene Chloride Polymers. Publication No. 57-9. Per Copy \$5.00.

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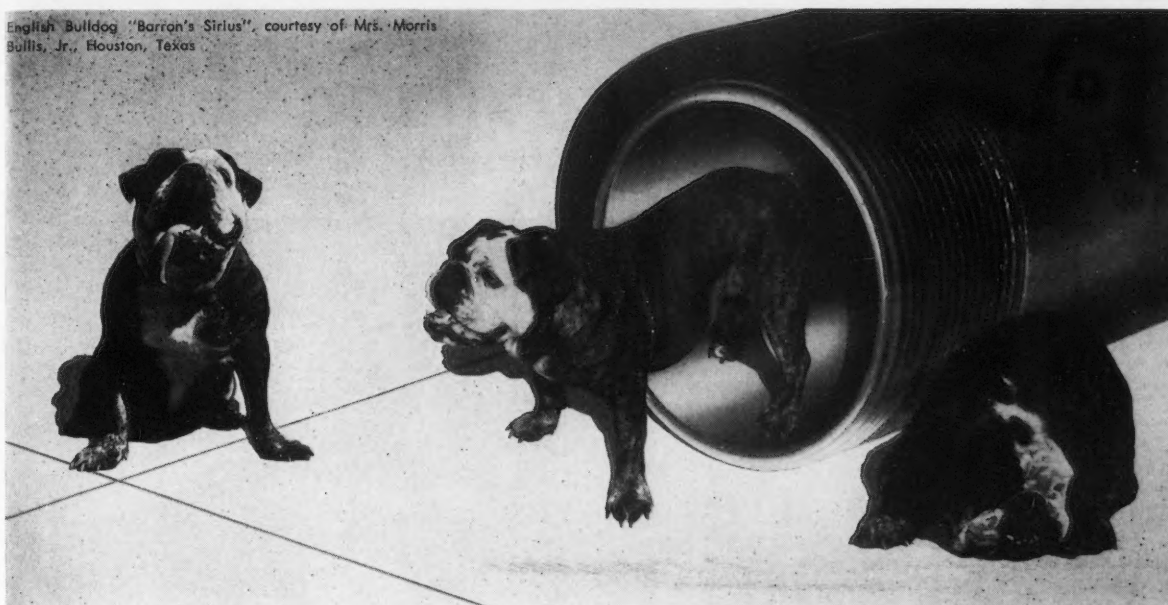
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1. Alphabetical subject and author indexes are published in December at the end of the calendar year volume of 12 issues.
2. Abstracts of articles appear in the Corrosion Abstracts section of CORROSION.
3. Abstracts of articles appear in the NACE Bibliographic Surveys of Corrosion.
4. Abstracts of articles appear in the Corrosion Abstract Punch Card Service.
5. CORROSION is Indexed regularly by Engineering Index.
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Figure 1—Route of the Trans-Arabian Pipeline.

Controlling External Corrosion On the Trans-Arabian Pipeline*

Introduction

CONSTRUCTION of the 30-31-inch distance of 20 feet from the piping, was completed in October 1950. It has four main pump stations, all in Saudi Arabia (Figure 1). The line begins at Qaisumah, Saudi Arabia and extends through Jordan and Syria, a total of 753.91 miles, to its Mediterranean terminal at Sidon, Lebanon. About 378.91 miles were laid below ground and 375.00 miles of pipe are above ground, supported by steel girders and concrete piers spaced at 65.6 foot intervals. The above-ground portion of the line lies entirely in Saudi Arabia and has hundreds of buried sections scattered along its length. The buried sections range from 30-foot crossings for camels to stretches of several miles in low areas. These buried sections of the line encounter many kinds of soils ranging from those of the dry desert with resistivities running up to hundreds of thousands ohm-centimeters to clays and loams as low as 800 ohm-centimeters.

Existing Treatment and Ditch Condition

All buried sections of the main line were given an application of a standard petrolastic primer followed by a coat of asphalt, a glass fiber floss, a second coat of asphalt and an outer wrapper of asbestos felt. In rocky areas, padding was used as a supplementary protection against rocks.

Subsequent inspections, however, revealed much of the pipe coating on the line to be of only fair quality. Inadequate bonding between the steel pipe

and coating exists along a major portion of the buried line. Poor bond apparently resulted more often from dead primer than from an accumulation of dust or foreign matter on the primed pipe, although signs of both are encountered.

Five years after cathodic protection had been continuously applied, a section of the main line, where pipe-to-soil potential was found appreciably lower than adjoining sections, was excavated and the coating inspected. Outwardly the coating appeared in good condition, with no evident holidays. However, stripping sections of the coating from the pipe revealed bond was lacking and that considerable moisture had collected between the line and coating for about 100 feet. Liquid would gather and drip out at the bottom of the strip points. A sample of this brown liquid was found to be a basic solution containing 17% sodium carbonate with a pH value of 11.5. Some areas between coating and line contained a white deposit; crystals, apparently of the same substance, were found near the bottom. No rust or corrosion products were evident. The average pipe-to-soil potential on this section was -1200 mv. This section is not typical of the buried line, but represents one type of condition, particularly in intermittent stream beds and other low areas, where water gathers during the rainy season.

Backfill on the line in the volcanic and mountainous areas of Jordan, Syria and Lebanon is rocky.

Coating conductivity varies considerably along the pipe line from as low as 10 micromhos per square foot to several hundred micromhos.

Corrosion Control on the Main Line

The cathodic protection program for

Abstract

Details are given of the cathodic protection system on the Trans-Arabian pipe line. Unattended crude oil burning Diesel-driven generator stations are used as source of rectifier power at points distant from terminals. Ground beds require watering during dry season. Silicon cast iron anodes will be used to replace steel-rail anodes in marine system protection. Barges, tugs, piers and buoys are protected by magnesium anodes.

the Trans-Arabian Pipe Line system was started as soon as the pipe was laid in the ground.

From Qaisumah, Tapline's first pump station, to Turaif, the last pump station, the line is above ground except for 133.19 miles of scattered buried sections of 30 feet to several miles in length. The entire section of 245.72 miles between Turaif and the Sidon terminal is buried.

The protection program originally called for the installation of rectifiers in the four pump stations and the Sidon terminal and of magnesium anodes on the intermediate sections.

Protection achieved from the 100 volt-70 ampere pump station rectifiers soon was found to be considerably more limited than early surveys indicated. The magnesium program on the short buried sections in high resistivity soils was generally found to be inadequate. The constant increase in current requirement due to progressive settling of backfill around the pipe and deterioration of the pipe coating, soon necessitated the establishment of cathodic protection stations at shorter intervals along the line.

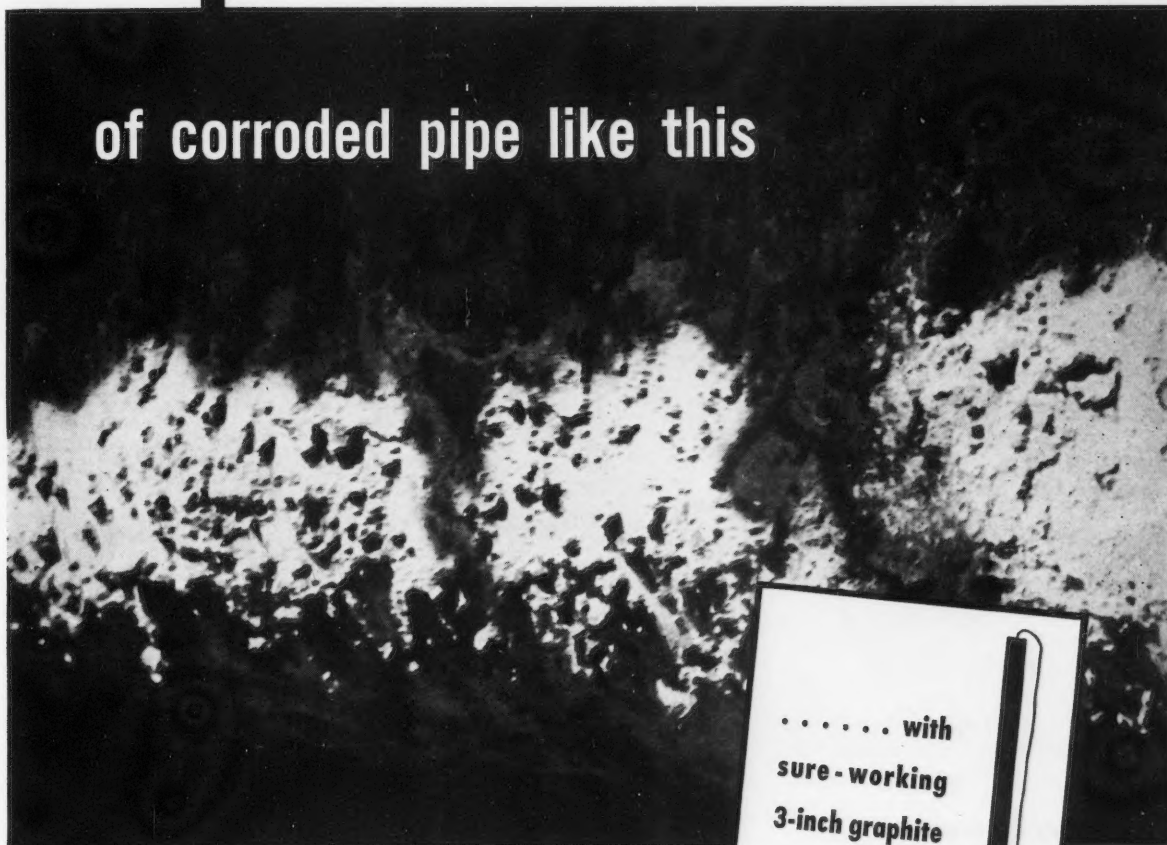
Power is not available along the line except from the pump stations and Sidon terminal. A power line along the entire length of the line would have involved a great deal of unnecessary expense. Diesel-driven generators were found to be the most economical source

(Continued on Page 102)

* A paper presented at the 13th Annual Conference, National Association of Corrosion Engineers, St. Louis, Mo., March 11-15, 1957 by E. M. Mansry, Trans-Arabian Pipe Line Co., Beirut, Lebanon.

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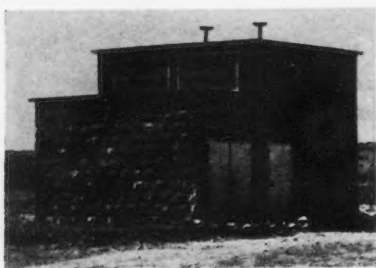


Figure 2—Unattended cathodic protection station in Jordan

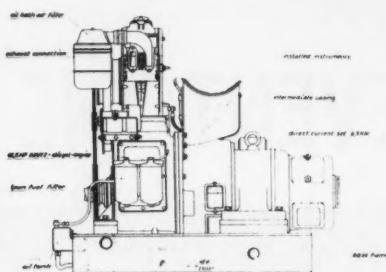


Figure 4—Deutz engine-generator unit.

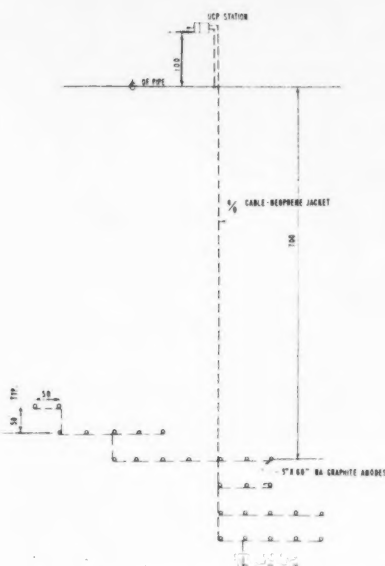


Figure 3—Layout of U. C. P. station ground bed design.

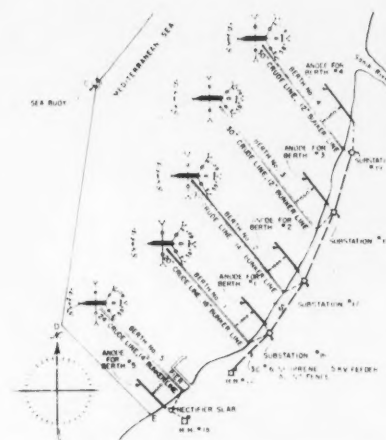


Figure 5—Cathodic protection system layout—submarine lines 1-5 inclusive.

Controlling External—

(Continued from Page 100)

of current for the cathodic protection of Tapline.

The effort was directed at first to protect the continuously buried section between Turaif and Sidon, a distance of 245.72 miles. The line goes through soft soil in Arabia and part of Syria, lava in Jordan and part of Syria, and rocky soil in Lebanon and the balance of Syria. Coating conductivities run high along this section and the coating is extensively damaged by rock.

The most economical spacing between cathodic protection stations, assuming an average coating conductivity of 250 micromhos per square foot and using the Finite Line equation,¹ was found to be 11 miles. This spacing normally would limit the potential at the drain point to three volts.

The terrain along this portion of the line is generally either rocky or of high resistivity soil particularly during the long dry season. This did not permit accurate spacing of the stations as specified in the theory. However, sites for all the would-be ground beds were located as close to the theoretical drain points as possible.

At present, the pipe line between Turaif and Sidon is protected from recti-

fier installations in Turaif, Qaryatayn and Sidon and 14 intermediate unattended Diesel-driven generator stations. (Figure 2). The ground beds (Figure 3) almost all require watering during the dry season. Water must be hauled up to 62 miles.

Unattended Cathodic Protection Stations

In the unattended cathodic protection stations Dornhoff generators are connected directly to single cylinder, air-cooled Deutz Diesel engines. Each generator is rated at 6.5 kw and is capable of continuous operation at as low as 40% of its rated voltage. New generators will be equipped with a 12-volt dynamo for field excitation to render the generator capable of operating at outputs ranging from 65 amperes at 100 volts to 162 amperes at 40 volts. This will meet the variable current requirements from summer to winter as well as from location to location. (Figure 4).

The engine could not be operated on the contemplated four-day schedule because capacity of the oil pan in the crankcase was insufficient for four days' continuous service and the valve rockers and valve guides in the cylinder head had to be lubricated by hand every day through a two-lid oiler mounted on the cylinder-head cap. To overcome these obstacles, an additional oil vessel was fitted and connected with a flexible tube to the oil pan. The oil was made to flow from the additional vessel to the oil pan and thus be sufficient for four days' operation.

Likewise, an extra vessel containing

lubricating oil for the valve rockers and valve guides was mounted on the wall with flexible connection to the lubricating nipples on the cylinder head cap. With these alterations the engines run four days without attention.

No. 2 Diesel fuel was used on the Deutz units installed during 1952 in Syria and Jordan. However, a crude oil test, made on one of the units installed in 1953, gave encouraging results. Only a few modifications were required from the manufacturer for crude oil operation. Engines now received in the field are equipped with special dual fuel filters, fuel feed pumps, pistons with cast iron insert and chrome compression rings and other minor features required for satisfactory crude oil operation. With the exception of four unattended cathodic protection stations in Syria, all the Deutz engines along Tapline now operate on crude oil tapped directly from the main line into a storage tank in each unattended cathodic protection station.

Each unattended station has two generating units. The units are operated alternately on a weekly cycle. This arrangement makes it difficult to provide a detailed operating record of any single unit. Nevertheless, the spare units assure 90 percent operation of the cathodic protection station. Direct current log hour meters are on order and soon will be installed in all unattended cathodic protection stations to record exact operation time.

No major mechanical trouble causing a shut down of any of the stations has been encountered. Periodic maintenance and overhaul programs for every unit are carried on.

Corrosion Control on the Short Buried Sections

The short buried sections of line between Qaisumah and Turaif were inadequately protected by magnesium anode installations.

In February 1955, Tapline experienced its first corrosion leak on the main line. The leak occurred on a buried section about 1600 feet long. Two other leaks followed in October and November of the same year, also in similar short buried sections.

Unattended cathodic protection stations with Deutz engine-generator sets then were installed to protect the underground sections of the line in Saudi Arabia. Seven such stations are now in operation.

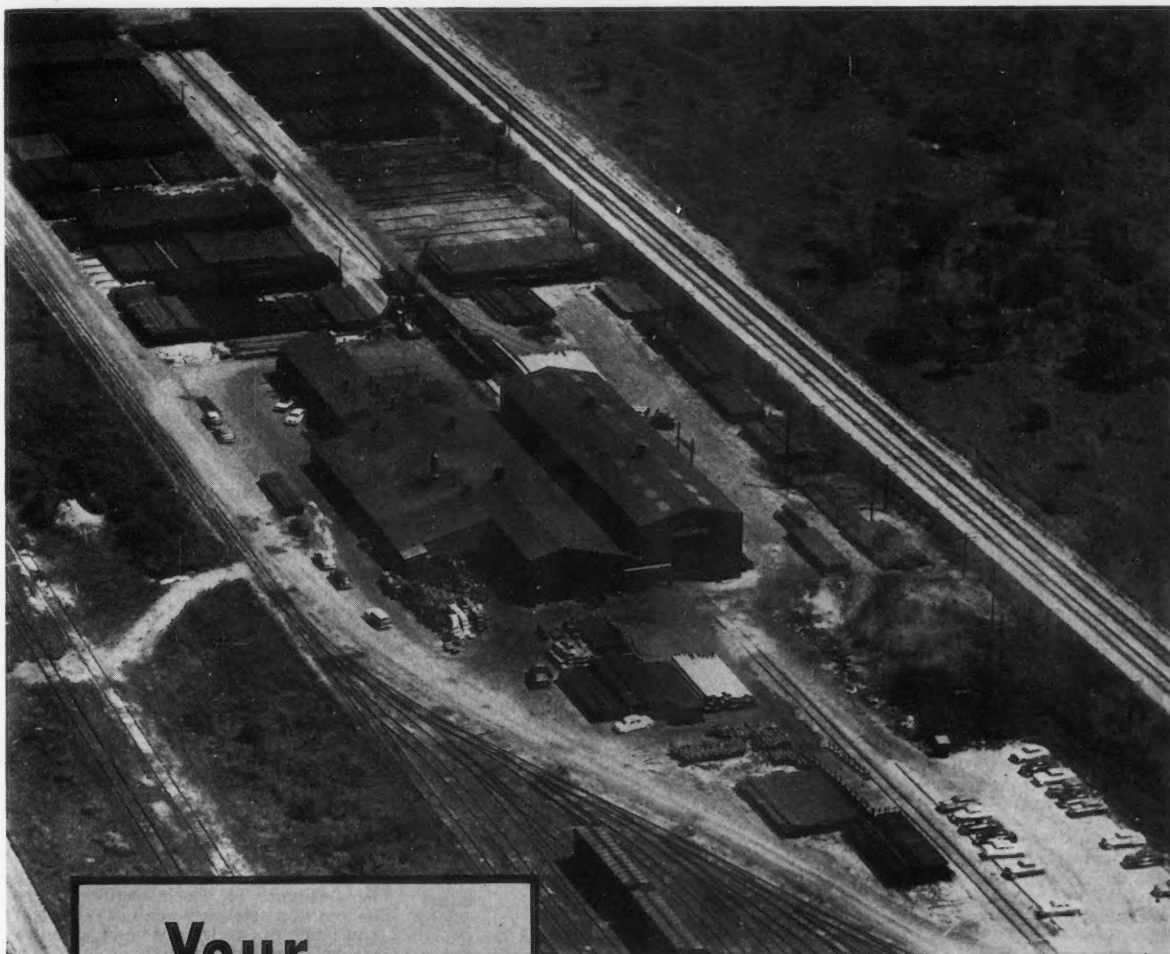
Corrosion Control in the Pump Stations

Numerous leaks occurred on the control and instrument lines in the pump stations. These lines had been receiving partial protection from the 100 volt-70 ampere rectifier at each station. Current drained had been insufficient to provide complete protection.

Principal areas of low pipe-to-soil potential are in the vicinity of the scraper traps and close to the pump house where all the instrument lines are located. Complete protection from a remote anode is usually uneconomical in such cases because:

1. There is a large area of bare steel in contact with the soil, and
2. The soil resistivities in these areas are too high to permit sufficient protective current to be drained from the piping.

(Continued on Page 104)



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Controlling External—

(Continued from Page 102)

The following program is in progress to ensure complete protection of the station piping:

1. All areas of low pipe-to-soil potential have been located by taking detailed measurements at 50-foot intervals in a grid pattern over the entire industrial area.
2. Supplementary protection will be provided by two 100 volt-25 ampere rectifiers connected to a number of graphite anodes distributed over all the low potential areas.
3. The anodes will be installed at a distance of 20 feet from the piping.

The current requirement from such a system is usually small, but a high voltage is required, because of the high soil resistivity.

Corrosion Control on Submarine Lines

The original marine system constructed in 1950 consisted of four loading berths with a crude line and a bunkering line connecting to each berth. The lines were wrapped with an asphalt treatment and covered with rock shield before laying. The lines are buried along the shore from a manifold at the shore control house, to the points where they take off to their respective berths. In August 1951, an additional submarine system was constructed for berth south of the original installations. The two lines were laid in about the same arrangement as the earlier systems, but the submerged portions were not given any external protection.

Cathodic protection is applied to the submarine lines by four 20 volt-250 ampere and 15 volt-200 ampere rectifiers (Figure 5). Each rectifier is connected to a steel rail anode 600 feet long consisting of two lengths of 45 pound rail welded together. Each anode lasts three years. An average of 150 amperes is applied to each berth.

In October 1956, ten 3 x 60-inch high silicon cast iron anodes were installed to replace the deteriorating steel anode for one of the berths. The anodes were connected by a 4/0 cable and laid parallel and 20 feet away from the existing steel anode. Grout bags were laid over the lead cable as it emerges from the water towards the shore to protect it from wave action. Silicon cast iron anodes will replace the steel anodes for all the submarine berths when the latter deteriorate because they are cheaper and easier to install.

All other marine facilities, such as the barges, tugs, buoys and piers are protected with magnesium anodes.

Reference

1. Ballou, Howell, Lilljeberg and Offerman. Proposed Alternative Method for Determining Electrical Resistance of Pipe Line Coatings. *Corrosion*, 7, 438-40 (1951).

APRIL TECHNICAL TOPICS

In Technical Topics April look for: "Impressed Current Anodes Installed and Back-Filled at Depth of 350 Feet" by Joe F. Tatum. This paper will be presented at the 14th Annual Conference at San Francisco.

Protective Coating Standardization in a Multi-Plant Chemical Operation by S. W. McIlrath.



CORROSION ABSTRACTS

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1. GENERAL

1.2 Importance

1.2.5, 4.3.2, 6.3.15, 3.8.3

Titanium Corrosion and Inhibition in Fuming Nitric Acid. H. B. BOMBERGER. *Corrosion*, 13, No. 5, 287t-291t (1957) May.

Evidence was found which indicates that sporadically rapid attack observed on titanium in red fuming nitric acid may, in some cases, be associated with a limited air supply in the test container. Additions of air, oxygen and certain salts resulted in noticeable corrosion inhibition. Attack in the uninhibited acid was found to be largely intergranular. In the case of a two-phase alloy the beta phase was removed preferentially, leaving a finely-divided pyrophoric deposit of the alpha structure. A possible mechanism

is proposed for the observed breakdown in passivity. 13842

1.2.5, 4.3.2, 6.3.15

Corrosion and Ignition of Titanium Alloys in Fuming Nitric Acid. JOHN B. RITTENHOUSE, NICHOLAS D. STOLICA, STEPHEN P. VANGO, JULIA S. WHITTICK AND DAVID M. MASON. U. S. Wright Air Development Center Materials Laboratory, Technical Report 56-414, February, 1957, 57 pp.

Corrosion rates increase with increasing nitrogen peroxide in the range 0 to 20% and decrease with increasing water in the range 0 to 2%. Ignition or pyrophoric reactions can be initiated by impact or friction after exposure to fuming nitric acid containing from 0 to 1.25% water and from 2.5 to 28% nitrogen peroxide for periods of time exceeding four hours.—BTR. 14120

1.6 Books

1.6, 6.5

Cast Metals. (In German.) ERWIN KNIPP. Book, 1956, 173 pp. Published by: Giesserei-Verlag G.m.b.H., Dusseldorf.

The author, a University lecturer, who in 1953 published a good book on Casting Defects, has—at the request of designers—compiled a reference book of tables which contain in abbreviated form the most important data on 472 different cast metals.

The five sections of the book give information on composition, castability, main uses, machinability, mech. & phys. properties, heat- and corrosion-resistance of 93 alloy cast irons, 10 malleable cast irons, 148 cast alloy steels, 100 non-ferrous casting alloys, 66 cast light alloys, and 55 bearing metals.

The author is aware that he still had to leave frequent gaps in his tables where no data or no reliable information could be found in the literature; he intends to fill them in gradually in future editions.

The reviewer has compared many of the items with other published information and has found the data to be consistently reliable.—MA. 13961

1.6, 6.5, 6.7.2, 5.2.1

Problems of Powder Metallurgy and Strength of Materials. Vol. III. (In Russian.) Institut Metallokeramiki i Spetsial'nykh Splavov, Akademii Nauk Ukrainskoy S.S.R. Book, 1956, 144 pp. Izdatel'stvo Akademii Nauk Ukrainskoy S.S.R., Kiev.

Contents: I. N. Frantsevich, Present-Day Problems of Powder Metallurgy; I. N. Frantsevich, Elastic Constants of Metals and Alloys; I. N. Frantsevich and D. F. Kalinovich, The Phenomenon of Electrical Transfer in Metallic Solid Solutions-I; V. N. Eremenko, V. M. Polyakova, and Z. P. Golubenko, The Reaction of Titanium Carbide with Nickel; V. N. Eremenko and N. D. Lesnik, The Reaction of Titanium Carbide with Cobalt; I. M. Fedorchenko, N. A. Filatova and N. N. Serega, A Comparative Study of the Properties of Iron Powders; G. K. L'vov, Production and Properties of Powder-Metallurgy Products in Aluminum; G. S. Pisarenko and V. V. Khil'chevskii, The Geometrical Parameters of the

Hysteresis Loop as Characteristics of the Damping Properties of a Material; V. G. Timoshenko, On the Use of a Capacity Device for Recording Mechanical Vibrations; I. N. Frantsevich, N. A. Pilinenko, and M. E. Lyashenko, On the Effect of the Cathodic Polarization of Steel Gas-pipes Under Conditions of Electrolytic Protection on the State of an Insulating Bitumen Coating; V. V. Grigor'eva, Titanium Carbide-Base Alloys Having Strength at Elevated Temperatures.—MA. 14001

1.7 Organized Studies of Corrosion

1.7.1, 2.5, 5.9.1, 5.3.3

Standardization in the Field of Corrosion and Corrosion-Protection in Germany. *Metall*, 9, No. 13/14, 593 (1955) July. Translation by Henry Hives, *Corrosion*, 13, No. 10, 625t-626t (1957) Oct.

The present status of German standardization relating to the corrosion, corrosion-protection by chemical, electrochemical or galvanic coatings and testing of metallic industrial materials is tabulated. Some basic information concerning the organization and progress of the work is presented. 14182

1.7.2

Corrosion Testing Stations of the French Iron and Steel Industry. *Aciers Fins et Speciaux*, No. 24, 10-14 (1956) Dec.

Survey of equipment and operating possibilities of corrosion testing stations of French steel industry. French contributions to study of corrosion of steel are discussed. Photographs, 13 references.—INCO. 13956

2. TESTING

2.3 Laboratory Methods and Tests

2.3.4, 6.3.17

Aqueous Corrosion of Uranium Fuel-Element Cores Containing 0 to 20 w/o Zirconium. DANIEL R. GRIESER AND EUGENE M. SIMONS. Battelle Memorial Institute, U. S. Atomic Energy Commission Publ., BMI-1156, January 7, 1957 (Declassified Feb. 28, 1957), 33 pp. Available from Office of Technical Services, Washington, D. C.

A description is given of the design and operation of a windowed autoclave system employed in the study of corrosion by pressurized hot water. The device has been used to obtain time-lapse motion pictures of the swelling and rupture of deliberately defected zirconium-clad uranium specimens. A method is described by which corrosion rates were calculated from pressure and temperature measurements. A typical set of pictures taken during a test is presented and corrosion rates are reported for uranium-0, 5, 10, 15 and 20 wt.% zirconium alloys subjected to 600 F water. (auth.)—NSA. 14301

2.3.5

Measurement of the Corrosion Rate of Iron by Polarization Techniques. W. J. SCHWERTFEGER. *J. Research National*

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Bureau of Standards, 58, No. 3, 145-153 (1957) March.

Corrosion-rate-measuring techniques previously shown to be applicable to low carbon steel exposed to corrosive soils apply to low and medium carbon steels in a sodium chloride solution having a concentration of 2000 parts per million. Corrosion-rate measurements can be made automatically by using a synchronously driven voltage divider and a 2-pen electronic recorder. Polarizing characteristics of high-silicon cast iron when exposed to a 2000 parts per million sodium chloride solution showed that corrosion rate becomes relatively low as corrosion reaction changes from cathodic to anodic control. Photos, graphs, tables.—INCO. 13835

2.3.5

Measurement of the Corrosion Rate of Iron by Polarization Techniques. W. J. SCHWEDTFEGER. *J. Research National Bureau of Standards*, 58, 145-153 (1957) March.

Techniques previously shown to be applicable to low-carbon steel exposed to corrosive soils are also shown to apply to low- and medium-carbon steels in a sodium chloride solution having a concentration of 2000 ppm.—BTR. 14166

2.3.5, 3.2.3, 6.3.6

Validity of Miley's Electrometric Method for the Qualitative Analysis of Oxidation Layers Formed on Copper. F. BOUILLON, J. PIRON AND M. DE LIL. *Nature*, 178, No. 4547, 1406-1407 (1956). Cf. de Brouckure et al., *Bull. Soc. Chim. Belges*, 60, 26 (1951). Cupric hydroxide can be electrochemically reduced only in an electrolyte that dissolves it. If sodium hydroxide is used, complex potential/time curves can be obtained with films consisting of only one compound.—MA. 13976

2.3.6

A Method for the Direct Examination of Metal Surfaces by Means of Electrons Generated by Ion Bombardment. G. MOLLESTEDT AND M. KELLER. *Rev. universelle Mines, Ser. ix*, 12, No. 10, 415-420; disc. 420 (1956). (In German.)

A technique is described for studying metal surfaces by an electron microscope incorporating an immersion-type electrostatic or magnetic objective and using electrons generated from the metal surfaces by ion bombardment; the resolving-power of the microscope is $\sim 500 \text{ \AA}$, while the theoretical limit with an optimum aperture is $\sim 100 \text{ \AA}$. The images show good contrast when the surface is maintained at 150 C. Illustrative examples of the surfaces of iron, copper, silver, tungsten, lead, nickel, platinum, aluminum and pearlitic steel are given. In the discussion, J. Nutting pointed out that, if reactive ions, e.g. nitrogen, are used in the microscope, there is the possibility of nitride formation when examining ferrous surfaces at 150 C; inert gases alone should be used. 7 references.—MA. 14091

2.3.6, 6.4.2, 3.7.4

Application of Electron Microscopy to the Study of Certain Aspects of Crystal Surfaces and the Nature of Intergranular Boundaries in Aluminium. (In French.) PIERRE BUSSY. *Publications Scientifiques et Techniques du Ministère de l'Air, Institut de Recherches Scientifiques et Techniques du Centre-Ouest*, No. 325, 1957, 72 pp.

A study of the substructures appearing on the surface of aluminum crystals.

Intercrystalline corrosion of aluminum in hydrochloric acid. Properties of grain boundaries.—BTR. 14246

2.3.7

Effect of Changing Cyclic Modulus on Bending Fatigue Strength. A. A. BLATHERWICK AND B. J. LAZAN. University of Minnesota. U. S. Wright Air Development Center, October, 1956, 129 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 121816).

A phenomenological study was made of the effect on fatigue strength of changes in the cyclic secant modulus, or the ratio of the maximum stress to the maximum strain of the cyclic stress-strain hysteresis loop. The research was undertaken in two parts. In the first, the implications of changing cyclic properties were analyzed by means of hypothetical cyclic stress-strain curves. The effects of cross-sectional shape of specimen and of loading conditions on fatigue strength were investigated through calculations based on the assumed material behavior. In the second phase, actual materials were tested in reversed-flexure to provide experimental verification of the results obtained in the hypothetical analysis. It was concluded that the type of material is exceedingly important in determining the effect of specimen shape and type of test on fatigue strength. 13973

2.3.7, 6.2.3

Methods of Notch-Toughness Testing of Ship Plate Steel. N. CHRISTENSEN AND B. AUGLAND. *Brit. Welding J.*, 4, No. 2 (1957) Feb.; *Welding Research Abroad*, 3, No. 3, 29-47 (1957) May.

Notch-toughness properties of 14 ship plate steels and a molybdenum-boron alloy steel were studied by means of various Charpy impact test methods by impact testing of bars in full plate thickness and by static tensile bend and slow bend methods. Relationships between measurements of energy absorption, lateral deformation and fracture appearance are reported for the various tests. Better approach to service failure conditions without preceding deformation was attempted in static tests by introducing narrow embrittled zone beneath sharp indentation. Arrest of brittle cracks originating from such notches were evaluated as criterion of fracture propagation transition. Temperature range of fracture and its relation to available elastic energy is discussed. Derivations of fracture arrest temperatures from transition temperatures based on Charpy impact data indicate that highly ductile, fully killed steels may not be able to arrest brittle fractures in proportion to their ability to resist fracture initiation. Tables, graphs, photomicrographs.—INCO. 14247

2.3.7, 6.3.15, 3.2.2

Effect of Testing Variables on the Hydrogen Embrittlement of Titanium and a Titanium-8% Manganese Alloys. R. I. JAFFEE, G. A. LENNING AND C. M. CRAIGHEAD. *Trans. Am. Inst. Mining Met. Engrs. (J. Metals)*, 206, No. 8, 907-913 (1956).

Using experimental techniques which are described, tensile and notch-bend tests have been carried out to determine the effects of testing speed, notches (with a stress-concentration factor of 3), and testing temperature (-196 to $+200 \text{ C}$) on the hydrogen embrittlement of (1)

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2.3.9

Electron Probe Microanalyzer and Its Application to Ferrous Metallurgy. R. CASTAING, J. PHILIBERT AND C. CRUSSARD.



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Paper before Am. Inst. Mining Met. Engrs., New Orleans, February, 1957. *J. Metals* (Trans. AIME), 9, No. 4, 389-394 (1957) April.

Short survey of first results obtained with fine-focus emission spectrometer demonstrating its variety of applications. Microanalyzer enables determination of all elements of atomic number greater than that of chlorine; by use of special counters, limit may be extended downward in atomic number to include aluminum and magnesium. Studies discussed include: segregation of manganese in tire and Hadfield steels; selective oxidation during scaling of open-hearth billet containing 0.22 nickel (enrichment of nickel found in metal surrounded by oxides, sulfides and silicates); internal oxidation of nickel-chromium alloys (diagram of oxidation mechanism is given); identification of sulfides and carbides (example is observation of niobium carbide in austenitic nickel-chromium-cobalt turbine blade steel); diffusion studies of uranium-zirconium and iron-copper systems; and analysis of oolite iron ore. Photomicrographs.—INCO. 14051

2.4 Instrumentation

2.4.2

Description of a New Aerosol Corrosion Test Chamber. (In German.) W. HESS, IVA Tidskrift for Teknisk-Vetenskaplig Forskning, 28, No. 1, 23-35 (1957). —BTR. 14308

2.4.2

An Apparatus for Investigating the Low-Pressure Oxidation Kinetics of Hot Metals. L. G. CARPENTER AND W. N. MAIR. *J. Sci. Instruments*, 34, 110-114 (1957) March.

The data of a typical titanium oxidation experiment are given.—BTR. 14054

2.4.2

The Potentiostat as a Metallographic Tool. C. EDELEANU, *J. Iron Steel Inst.*, 185, Pt. 4, 482-488 (1957) April.

Discussion of use of potentiostat, an instrument which can maintain potential of working electrode at any desired value, in metallographic studies. Description is given with some nickel-chromium stainless steels of ability to use instrument for controlled etching, for detection of susceptibility to intercrystalline corrosion and in study of phase diagrams. Graphs, photomicrographs, tables, 10 references.—INCO. 14118

2.4.2, 2.3.4

New Methods of Studying Corrosion at Elevated Temperatures. J. BREFORT AND G. VALENSI. Paper before 1st Congrès Européen de la Corrosion, Paris, Nov., 1956. *Corrosion et Anticorrosion*, 5, 106-111 (1957) April.

Description of new thermo-balance, developed at Poitiers for study of dry corrosion, which loads up to 200 g. with a sensitivity of 0.1 mg. and automatically registers time and mass by means of a photo-voltaic cell. Notes on ancillary equipment, details of method for studying dry corrosion and data on corrosion of silver by molten and vaporized sulfur are given.—INCO. 14241

2.4.3, 7.10

Radiographic Inspection of the Structure of Lifting Chains. G. A. HOMES AND R. PANKOWSKI. Paper before Société Française de Métallurgie, Autumn Mtg. *Metal Treatment & Drop Forging*, 24, No. 139, 143-148 (1957) April.

Describes non-destructive test method whereby embrittlement may be detected and

measured on wrought iron and steel lifting chains. Application of radiospectrography to inspect annealing of chains, study of heterogeneity of cold work along surface and depth of link, correlation between stress applied to material and half-width of diffraction ring and correlation between distribution of cold work and breakages in service are discussed.—INCO. 14128

2.4.3, 5.3.2

Latest Methods for Inspecting Lead Linings. K. H. ROLL. *Chem. Eng.*, 63, No. 11, 248-258 (even pages), (1956) Nov.

Lead linings are inspected for the presence of pinholes or porosity in welded seams on sheet linings; hairline cracks either in weld or sheet resulting from fatigue or stress corrosion; and pinholes, inclusions or bond discontinuities in the case of clad vessels. Fluorescent penetrant, dye penetrant, acid wash test, ultrasonic and radiographic methods.—BNF. 13688

2.5 Specifications and Standardization

2.5, 8.4.5, 1.2.5

Corrosion Testing of Zirconium, Zircaloy and Hafnium. J. S. THEILACKER. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., AECU-3260, March 9, 1956 (Revised May 26, 1956), 6 pp. Available from Office of Technical Services, Washington, D. C.

Specifications are given for the corrosion testing of core components and for quality control coupons. Procedures for testing, handling of equipment and precautions for handling radioactive materials are discussed. A schedule is presented for the testing of various items. 13718

3. CHARACTERISTIC CORROSION PHENOMENA

3.1 General

3.1, 5.1

An Approach to the Corrosion Problem. ANTON DE S. BRASUNAS. *Corrosion Technology*, 3, 261-265 (1956) August.

Nature of corrosion attack, corrosion principles and rates, mitigation.—MR. 13592

3.1, 5.1

Corrosion: Types and Prevention. C. L. HIBERT. *Product Engineering*, 27, No. 11, C6-C11 (1956) Mid-October.

This is a general description of the mechanics of corrosion in one metal, between dissimilar metals and between metals and nonmetals. Corrosion begins on the surface of the metal where it is exposed to corrosive environment. The following types of corrosion are described: uniform etch, pitting, intergranular and exfoliation. Identification of the mode of attack and means of treatment may be classified as follows: Local cell corrosion; galvanic cell corrosion; concentration cell corrosion. Each type of corrosion is discussed at length. Since the progress of corrosion depends on a media in the liquid phase, this rate tends to increase with an increase in temperature until the air is boiled out of the solution. High temperature aids in evaporating the liquid under environmental conditions, therefore corrosion is less in hot dry climates and more in sea coast areas. When the corrosive media change from

liquid to solid state, corrosion is no longer possible. However, alternate heating to elevated temperature and cooling will hasten corrosive activity. Protective measures include painting, plating, coatings, sprays and others.—ALL. 14089

3.2 Forms

3.2.3, 6.3.6

Dry Oxidation of Copper Manganese Alloys. (In French.) F. BOUILLON AND M. JARDINIER. *J. Chim. Phys.*, 53, No. 10, 817-822 (1956) October.

Formation of oxides at various temperatures. A mechanism is postulated to explain the slowing down of oxidation when manganese enters the copper lattice between 110 and 320 C.—BTR. 13536

3.2.3, 3.8.4, 6.3.4

Effect of Oxygen Pressure on the Oxidation Rate of Cobalt. DONALD W. BRIDGES, JOHN P. BAUR AND W. MARTIN FASSELL, JR. University of Utah. *J. Electrochem. Soc.*, 103, 614-618 (1956) Nov.

Cobalt was oxidized from 800 to 12,000 C in 0.013-27.2 atm oxygen. It oxidized in accordance with the parabolic rate law above 950 C and formed the single oxide, CoO, above 900 C. Pressure increase accelerated the rate of oxidation. However, the oxidation rate eventually ceased to increase with increase of oxygen pressure at temperatures below 1150 C. Theoretical considerations employing a vacancy saturation mechanism correlated the data. Photomicrographs of the oxide layer are included. Activation energy for the diffusion process is 58,000 cal. 13529

3.2.3, 6.2.2

Identity of the Cubic Oxide Present in Films on Iron. D. E. DAVIES AND U. R. EVANS. *J. Chem. Soc.*, 1956, 4373-4375.

Some doubt has been felt about the possibility of distinguishing members of the series of cubic iron oxides of which Fe_2O_3 and $\gamma\text{-Fe}_2\text{O}_3$ are end members. New experiments show that the additional lines characteristic of $\gamma\text{-Fe}_2\text{O}_3$ appear when the transition $\text{Fe}_2\text{O}_3 \rightarrow \gamma\text{-Fe}_2\text{O}_3$ is about 80% complete. Iron, heated in hydrogen (to destroy the original film) and then exposed to oxygen, develops films which are close to $\gamma\text{-Fe}_2\text{O}_3$ if formed at room temperature, but contain more iron if formed at higher temperatures, approaching Fe_2O_3 . X-ray diffraction was used in the study of the powders and electron diffraction for the films.—RPI. 13525

3.2.3, 6.3.6

Oxidation of (OFHC) Copper to Cu_2O and CuO (600-1000 C and 0.026-20.4 atm. Oxygen). D. W. BRIDGES, J. P. BAUR, G. S. BAUR AND W. M. FASSELL, JR. *J. Electrochem. Soc.*, 103, No. 9, 475-478 (1956) Sept.

Correlation of weight gained with time and temperature; quantitative X-ray diffraction analysis of scale; effect of pressure variation on magnitude of parabolic rate constant. 18 references.—BNF. 13522

3.2.3, 6.3.9, 6.3.16

Results of Research on the Kinetics of Oxidation of Molybdenum and Tungsten and on the Nature of the Oxides

Produced. (In French.) K. M. GORBUNOVA AND V. A. ARSLAMBEKOV. *J. Chim. Phys.*, 53, No. 10, 871-883 (1956) Oct.

Research on oxidation at ordinary and high temperatures conducted by manometric and gravimetric methods.—BTR. 13608

3.2.3

Kinetics of Formation of Porous or Partially Detached Scales. C. E. BIRCHENALL. *J. Electrochem. Soc.*, 103, No. 11, 619-624 (1956) Nov.

Theoretical growth rates of oxide scales on metals are shown to be affected by the development of porosity. Simple models (e.g., pores assumed to grow at metal-oxide interface or entirely in the oxide) are considered.—BNF. 13508

3.2.3

The Tarnishing of Metals. (In French.) P. HUYSKENS. *Ind. Chim. Belge*, 21, No. 11, 1171-1192 (1956) November.

The action of oxygen, sulfur, and halogens on metals gives rise to the formation of films which can follow linear, parabolic, or logarithmic laws.—BTR. 13622

3.2.3, 6.2.1

Selective Oxidation of Iron-Chromium Alloys in the Vicinity of the Dissociation Equilibrium of Cr_2O_3 . (In French.) J. MOREAU AND J. BENARD. *J. Chim. Phys.*, 53, No. 10, 787-797 (1956) Oct.

Thermodynamic study of selective oxidation and preparation and treatment of various high purity iron-chromium alloys. Examination of oxide formation and of the superficial structure of the metal; description of the three fields obtained.—BTR. 13694

3.2.3

Scaling of Pure Iron and Scaling in General. (In German.) NORBERT G. SCHMAHL, HANS BAUMANN AND HERMANN SCHENCK. *Arch. Eisenhüttenw.*, 27, No. 11, 707-713 (1956) Nov.

Experimental data on scaling of electrolytic iron with oxygen at 910 to 950 C. Excess temperatures caused by the heat of reaction of the scaling process are recognized as the reason for deviations from the parabolic scaling law. 28 references. 13674

3.2.3, 6.3.20, 3.5.9

Scaling of Zirconium at Elevated Temperatures (Technical Progress Report No. 3). E. B. EVANS AND W. M. BALDWIN, JR. Case Institute of Technology. U. S. Atomic Energy Comm. Pubn., AECU-3386, Dec., 1956, 32 pp. Available from Office of Technical Services, Washington, D. C.

To obtain a clearer understanding of the scaling mechanism additional studies were conducted on the effect of metal purity, specimen thickness and specimen shape on the magnitude of growth; the distribution of the gas to scale and to metal during scaling in various atmospheres; and the course of scaling (instantaneous scaling rates) in transferring from one atmosphere to another. In addition, a mechanism is proposed to fit the known facts concerning the scaling behavior of zirconium. The procedures employed are given in detail in the first technical report. (auth).—NSA. 13585

3.2.2

Factors Involved in Brittle Fracture. M. W. LIRHTNER AND R. W. VANDERBECK. U. S. Steel Corp. Paper before Am. Iron Steel Inst., Pittsburgh Regional Tech.

Mtg., Nov. 28, 1956. *AISI Reg. Tech. Mtgs.*, 1956, 427-483.

Value of notch toughness test lies in extent to which results obtained from it correlate with service behavior. V-notch Charpy test and crack-starter drop-weight test are best available for evaluating ability to resist brittle behavior. Mechanical factors affecting transition temperature are composition and microstructure. In pearlitic carbon steels, principal means of lowering transition temperature through changes in composition are by adjustments in carbon, manganese, silicon and aluminum. Both grain size and nature and distribution of carbide aggregates have appreciable effects on transition temperature of steel. Nickel imparts an added increment of toughness at low temperatures whether matrix microstructure is pearlitic or martensitic. Suitable emphasis should be placed on all three factors, material, design and fabrication, to obtain optimum performance in most economical manner. Steels tested include manganese-vanadium-titanium, 0.30 nickel steel, 8630 and 1.03 and 0.83 nickel steels. Tables, graphs, 53 references.—INCO. 14095

3.2.2, 1.4

Pitting in Ferrous Systems, An Annotated Bibliography. M. BENTON, compiler. U. S. Naval Research Laboratory, Bibliography No. 11, June, 1957, 117 pp.—INCO. 14214

3.2.2, 3.5.8

Sulfide Corrosion Cracking of High Strength Bolting Material. DONALD WARREN AND G. W. BECKMAN. *Corrosion*, 13, No. 10, 631t-646t (1957) Oct.

The sulfide corrosion cracking behavior

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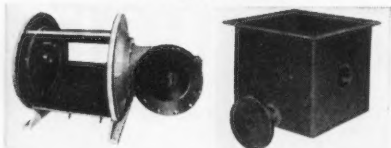
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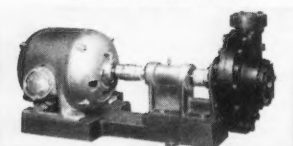


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of Type 4140 bolts was studied in hydrogen sulfide-water systems at temperatures of 20 to 120 C and at pressures of 1 to 17 atmospheres. The susceptibility to cracking increased with increasing bolt hardness, increasing applied stress, increasing amounts of plastic deformation and decreasing test temperature. Other bolting materials such as Inconel, Inconel-X, K-Monel and annealed Type 316 stainless steel were completely resistant to sulfide corrosion cracking.

The use of protective metallic coatings and the addition of corrosion inhibitors to the test system were evaluated as means of preventing the sulfide corrosion cracking of Type 4140 bolts.

The sulfide corrosion cracking of Type 4140 bolts is believed to be best explained on the basis of hydrogen embrittlement. 14235

3.2.2, 3.5.9

Filamentary Growths on Metals at Elevated Temperatures. S. M. ARNOLD AND S. E. KOONCE. *J. Applied Physics*, 27, 964 (1956) August.

A letter.

13972

3.2.2, 3.7.3, 6.2.4, 6.2.3

An Investigation of the Fracture of Light-Rolled-Steel Sections. K. J. PASCOE. *Brit. Welding J.*, 4, No. 3, 133-146 (1957) March

To determine behavior of light welded structures made from high-tensile structural steels and mild steel which are liable to cleavage-type fracture, study was made of effects of discontinuities normally present in welded structures on incidences of such fractures. Lengths of light sections (joists and channels) of mild steel, Ducol W 27 and a boron steel which included machined notches, weld runs, etc., were loaded in bending at 0 and -60 C. Results were correlated with notch-bend tests on specimens prepared from sections. Results indicate that machined notches and in some cases welds, particularly those laid with excessive current, would start fractures and if temperature were below ductile-brittle transition temperature fracture would be cleavage-type with little previous ductile bending of section. Repeated loading tests showed that fracture may start at considerably lower loads with only few applications of load. Tables.—INCO. 14176

3.2.2, 6.2.1, 3.5.8

Hydrogen Absorption, Embrittlement and Fracture of Steel. A Report on Sponsored Research on Hydrogen Sulfide Stress Corrosion Cracking Carried on at Yale University, Supervised by NACE Technical Unit Committee T-1G on Sulfide Stress Corrosion Cracking. ARNOLD E. SCHUETZ AND W. D. ROBERTSON. *Corrosion*, 13, No. 7, 437-458t (1957) July.

Results of a four-year research program at the Yale University Metallurgy Department are presented. After a review of the problems associated with spontaneous fracture of steels in sour gas condensate wells an account of the investigation is given as follows:

Part 1. Hydrogen sulfide embrittlement was compared with that caused by cathodic charging. An investigation was made of spontaneous fracture under conditions of constant deformation, as dependent on alloy composition, heat treatment, plastic deformation and chemical environment.

Part 2. Hydrogen absorption by iron-nickel alloys from hydrogen sulfide was compared to that from sulfuric acid.

Part 3. Permeation rate of hydrogen through austenitic, martensitic and ferritic

states of iron-nickel alloys was measured.

Part 4. Time dependence of static fracture of iron-nickel alloys as a function of applied stress, structure and hydrogen concentration was evaluated.

The following conclusions are given: Basic cause of failure is absorption of hydrogen. Principal factors in service failure are internal stress, magnitude of applied stress and hydrogen content. Both martensitic and ferritic structures fail when the stress level and hydrogen content are sufficiently high. Trace amounts of carbon, oxygen and nitrogen in 10% nickel steel have no detectable effect on failure. Adoption of limiting strength or hardness below which fracture does not occur in constant deformation tests is unreliable in predicting service life.

Because it is impractical to lower operating stress significantly below apparent "endurance limit" the remaining alternative is reduction of hydrogen concentration in the steel. Deadload tests in the environment must be made before safe operating procedures can be defined. 13892

3.2.2, 6.2.4

Crack Initiation in Hydrogenated Steel. H. H. JOHNSON AND A. R. TROIANO. Case Institute of Technology. *Nature*, 179, No. 4563, 777 (1957) April 13.

Existence of true incubation period for crack initiation is indicated by electrical resistance measurements on hydrogen-charged notched specimens of 4340 steel, plated with cadmium and baked to produce uniform distribution of hydrogen. Upon loading immediate increase in resistance was noted, resulting from decrease in notch area by deformation. Resistance then remained constant (incubation period), followed by increase in resistance due to crack initiation and propagation. Existence of incubation period is compatible with two major theories of hydrogen embrittlement (Zappfe and Petch and Stables). Length of incubation period depends upon average hydrogen concentration and is independent of applied stress.—INCO. 14122

3.2.2, 6.2.4

Crack Propagation in the Hydrogen-Induced Brittle Fracture of Steel. W. J. BARNETT AND A. R. TROIANO. Paper before Am. Inst. Mining Met. Engrs., New York, February, 1957. *J. Metals* (Trans. AIME) 9, No. 4, 486-494 (1957) April.

Macroscopic features of hydrogen-induced static fatigue in 4340 steel were identified. Electrical resistance method was developed to permit analysis of crack growth kinetics. Three distinct stages of the process were observed: 1st stage was characteristic of crack growth through pre-existent hydrogen-rich region (surface layer), 2nd stage was associated with gross inward diffusion of hydrogen and 3rd stage was associated with imminent fracture. Crack propagation appeared to be dependent on some critical combination of stress and hydrogen concentration. Mechanism based on strain induced trapping of hydrogen was proposed as explanation of pre-cracking on subsequent static fatigue behavior and effect of stress on 2nd stage crack growth rate. Tables, graphs.—INCO. 14059

3.2.2, 6.2.5

Selective Dissolution of Iron-Chromium-Nickel Alloys. H. HATWELL. *Compt. Rend.*, 244, 340-343 (1957) January 14.

Study of "honeycomb" corrosion of nickel-chromium-iron alloys, especially after heat treatment permitting intercrystalline precipitation of a phase (chromium carbide) richer in chromium than

the matrix. Honeycomb corrosion is deep attack (anodic, or by reducing acid) near grain boundaries. Supporting data are given on 25/20 steel.—INCO. 14162

3.2.2, 6.3.6

On the Mechanism of Intercrystalline Cracking (in Copper). (In English.) C. W. CHEN AND E. S. MACHLIN, *Acta Metallurgica*, 4, No. 6, 655-656 (1956).

A letter. Experiments on bicrystals of pure copper have shown that grain-boundary shear is necessary for the production of boundary voids. A mechanism is proposed in which tensile stresses are developed at jogs in the boundary during slip.—MA. 13954

3.2.2, 6.3.15

Hydrogen Contamination in Titanium and Titanium Alloys. Pt. III. Strain Aging Hydrogen Embrittlement in Alpha-Beta Titanium Alloys. HARRIS M. BURTE. U. S. Wright Air Development Center, Tech. Rept. 54-616 (Pt. III), October, 1956, 50 pp.

Hydrogen contamination in alpha-beta titanium alloys can lead to sudden, brittle fracture during the use of these materials. The strain aging embrittlement which causes such fractures was investigated. Strain aging hydrogen embrittlement in alpha-beta titanium alloys has its greatest effect on mechanical properties measured at slow strain rates. It can cause low ductility in room temperature tensile tests and premature brittle fracture in room temperature rupture tests. Fracture due to this process tends to be intergranular. Metallographic examination of many hydrogen contaminated alpha-beta alloys shows no evidence for a third phase either before or after fracture. In at least one alloy a third phase was visible after fracture. Both alloy composition and micro-structure affect susceptibility to strain aging embrittlement. Increasing test temperature seems to decrease the tendency towards embrittlement, but increases the rate at which embrittlement can occur. A mechanism for strain aging embrittlement is proposed. Other types of embrittlement which may be caused by hydrogen are mentioned. (auth.).—NSA. 13971

3.2.2, 6.4.2, 8.3.5

An Explanation of "Pin-Holing" of Light Gauge Aluminum Cooking Utensils. P. M. AZIZ. *Corrosion*, 13, No. 8, 536t-538t (1957) August.

The cause of pinholing or rapid perforation of light gauge aluminum cooking utensils has been studied by measuring the individual pit currents delivered by pitted discs mounted in the walls of cooking utensils. These currents, which are directly related to the pitting rate, were measured throughout the duration of the cooking cycle and the subsequent storage period. It was found that in some of the acid foods the steady state currents were more than ten times as great as in tap water and were large enough to account for the rapid perforation of light gauge cooking utensils sometimes observed in practice. Thus there is no reason to assume that defective metal had been used in these cases. It is recommended that foods of an acid nature should not be stored in aluminum utensils after cooking. 14005

3.2.2, 6.2.5

Further Studies on Stainless Steel Hot Cracking. P. P. PUZAK AND H. RISCHALL. Paper before Am. Welding Soc., Nat'l. Fall Mtg., Cleveland, October 8-12, 1956. *Welding J.*, 36, No. 2, 57s-61s (1957) Feb.

Test data provide additional evidence supporting the hypothesis that grain boundary liquation is responsible for base-metal hot cracking of stainless steels. Results are presented for Type 347 (established previously to be most susceptible) and Type 304 (not susceptible). Liquidus and solidus temperatures were obtained by thermal analysis techniques. Hot ductility and strength developed in high-temperature tensile tests conducted in temperature range below region of normal incipient melting (2100-2600 F) were determined to be of low order for those heats which exhibited base-metal cracking. Results of microscopic examinations and x-ray studies for identification of liquation constituents are presented. Eutectic-type mixture of carbides and nitrides of niobium with minor amounts of manganese, silicon and iron

comprise segregate involved in liquation cracking of Type 347 alloys. Tables, graphs, photomicrographs.—INCO. 13857

3.2.3

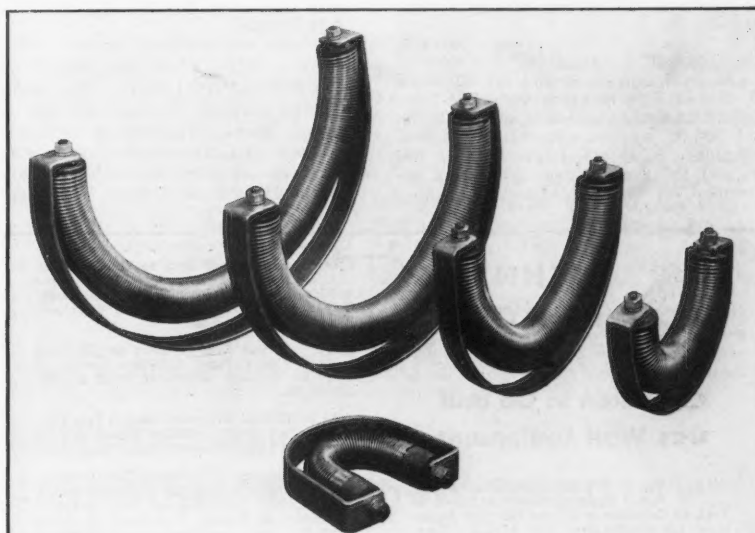
Scale Formation. (In Czech.) PAVEL GROBNER. *Hutník*, 6, 364-366 (1956) Dec.

The causes of scale on steel; its structure; effects of heat; chemical reactions; effects of alloying elements.—BTR. 13992

3.2.3

The Effect of Oxidation on the Surface Composition of High-Temperature Alloys. F. MALAMAND AND G. VIDAL. *Recherche Aeronaut.*, No. 56, 47-57 (1957) Feb.

Study of changes in composition of surface layers of Nical D, Nimonic 75, 80 and 95, 18/8 chromium-nickel stain-



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less steel, during oxidation in air was made with spectrographic technique. Depletion in chromium, titanium and aluminum contents was observed in surface layers of the Nimonic alloys. Effects of these surface compositional changes on stress-rupture and fatigue behavior is discussed.—INCO. 14132

3.2.3, 3.4.3,

Topochemical Studies of Corrosion Phenomena. (In French.) W. FEIT-KNECHT. *Corrosion et Anticorrosion*, 5, 36-50 (1957) Feb.

Properties and structure of solid corrosion products determined by means of the electron microscope and X-ray diffraction. Studies of oxide and other types of corroded layers on copper and zinc.—BTR. 14074

3.2.3, 6.2.1, 6.3.10

Oxidation of Iron-Nickel Alloys. Part II. Electron Diffraction at High Temperature. R. T. FOLEY, C. J. GUARE AND H. R. SCHMIDT. *J. Electrochem. Soc.*, 104, No. 7, 413-417 (1957) July.

The oxidation of iron-nickel alloys of 30, 41 and 78% nickel content has been studied at temperatures of 600, 700, 800 and 900 C by the electron diffraction technique. A special furnace was developed for the electron diffraction instrument for these experiments.

Usually more than one oxide was present on the alloy at these elevated temperatures. Unlike the conclusion drawn from exclusively room temperature observations, the predominant oxide on the 30% and 41% nickel alloys was the ferrite (Fe_3O_4 or NiFe_2O_4) rather than $\alpha\text{-Fe}_2\text{O}_3$. At 700 and 900 C both nickel oxide and molybdenum trioxide exist on the 78% alloy. (This alloy contains 3.8% molybdenum.) The presence of molybdenum trioxide above its melting point and where it exerts considerable vapor pressure is difficult to explain.

In some cases the lattice spacings of the alloy structure are carried over into the first formed oxide film. With subsequent growth the spacings achieve the normal (x-ray) values for the oxide. 14271

3.2.3, 6.2.2

The Growth of Ferrous Sulfide on Iron. R. A. MEUSSNER AND C. E. BIRCHENALL. *Corrosion*, 13, No. 10, 677t-689t (1957) October.

The rate of growth of ferrous sulfide on iron in sulfur vapor was studied between 650 and 900 C with sulfur vapor pressures between 10 and 500 mm of mercury. When differences in conditions are taken into account, the rates seem to be substantially higher than those found by Hauffe and Rahmel. The behavior of inert markers and the sulfidation of eutectic mixtures of iron and ferrous sulfide indicate that the iron ion is much more mobile in ferrous sulfide than is the sulfide ion. Self-diffusion coefficients for the iron ions were calculated approximately, assuming that Wagner's theory of scale growth is applicable.

The markers were often found a considerable distance from their expected location at the metal-sulfide interface. This has been attributed to cracking at the interface in some cases and to interference with growth by the markers in other cases. It has been shown that non-reactive inclusions slow down the rate of sulfidation. 14225

3.2.3, 6.2.4

Variations in the Structure Across the Thickness of the Scale on Nickel Steels. K. SACHS. *J. Iron Steel Inst.*, 185, 348-357 (1957) March.

The inner layers of the scales formed by various treatments on specimens of nickel steel were examined by a number of different methods. It was found that both the amount of metal in the scale and the over-all nickel content pass through a maximum at some distance from the metal core; no nickel was found outside the dimensions of the original specimens, except in one case. The scale near the core consists of wustite and metal enriched in nickel. 13 references.—MR. 13850

3.2.3, 6.2.5

The Formation of Oxide Films on Chromium and 18 Chromium-8 Nickel Steels. H. J. YEARIAN, W. D. DERBYSHIRE AND J. F. RADAVICH. *Corrosion*, 13, No. 9, 597t-607t (1957) Sept.

The formation of oxide films on simple chromium steels and 18-8 stainless steels oxidized in air at temperatures of 300 C to 700 C has been studied by electron microscopy, electron diffraction and X-ray diffraction methods. A thin uniform film forms in the first few minutes of oxidation and grows very slowly thereafter. As oxidation proceeds the protectiveness of the base film fails at randomly distributed positions, permitting the rapid growth of localized polycrystalline nodules of oxide. These nodules continue to grow and new ones are formed until the base film is completely covered. The rate at which the process proceeds depends on alloy composition and temperature in the same way as does the scaling rate at higher temperatures.

There is no evidence that the failure is due to cracking of the base film. There seems to be no detrimental effect produced by the usual amounts of minor constituents in the alloys. Local failure may be due to blistering or recrystallization.

The principal component of the base film is a solid solution of ferric and chromic oxides preferentially oriented with the (111) plane parallel to the surface. The degree of the orientation and the chromic oxide content of the solution increase with time of oxidation. A small amount of spinel may be present also. In the case of the 18 chromium-8 nickel alloy the spinel contains some nickel. The nodules are principally a ferric oxide or a low chrome ferric-chromic oxide solution and contain somewhat more spinel than does the base film. 14218

3.2.3, 6.2.5, 6.3.10

An Investigation of Intergranular Oxidation in Stainless Steels and High-Nickel Alloys (Period Covered: April 30, 1955 to June 30, 1956). CLARENCE A.



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SIEBERT, MAURICE J. SINNOTT, LYNN H. DESMYTER AND HARRY M. FERRARI. Engineering Res. Inst., Univ. of Michigan. U. S. Wright Air Development Center, Tech. Rept. 55-470 (Pt. 2), July, 1956, 52 pp.

Specimens from Chromel ASM, Hastelloy B and commercial and vacuum-melted Type 310 stainless steel alloys were oxidized for 100-hr. periods in the stressed condition. Intergranular oxidation measurements were obtained microscopically. In general, the intergranular penetrations increased rapidly with stress after a certain minimum for each alloy at various temperatures. The weight gained during oxidation was determined. It was found that most of the alloys tested followed the parabolic oxidation law. (auth)—NSA. 14007

3.4 Chemical Effects

3.4.3, 3.2.1, 1.4

Bibliographies of Corrosion Products. Section II. NACE Technical Unit Committee T-3B on Corrosion Products (A. H. Roebuck, chairman). *Corrosion*, 13, No. 9, 565t-570t (1957) Sept.

Selected abstracts are given on the identification and composition of corrosion products on aluminum, lead and lead alloys, silver, tin and tin alloys and magnesium. Included are 37 abstracts on aluminum; 19 on lead and lead alloys; 15 on silver; 26 on tin and tin alloys and 21 on magnesium.

Part 6. Aluminum Corrosion Products. Prepared by W. L. Fink, Aluminum Company of America; J. K. McBride, Aluminum Company of America; and Hugh P. Godard, Aluminum Laboratories, Limited.

Part 7. Lead and Lead Alloys Corrosion Products. Prepared by D. L. Hawke, National Lead Company.

Part 8. Silver Corrosion Products. Prepared by H. A. Finch and R. T. Foley, General Engineering Laboratory, General Electric Company.

Part 9. Tin and Tin Alloys Corrosion Products. Prepared by D. A. Vaughn, Battelle Memorial Institute and E. L. Koehler, Continental Can Company, Chicago, Illinois.

Part 10. Magnesium Corrosion Products. Prepared by F. N. Alquist and J. L. Wasco, Dow Chemical Company, Midland, Michigan. 14195

3.4.9, 3.2.2

Some Unusual Effects of Hydrogen in Corrosion Reactions. J. E. DRALEY AND W. E. RUTHER. *J. Electrochem. Soc.*, 104, No. 6, 330-333 (1957) June.

Consideration of corrosion in the presence of water has led to the postulation of damage by hydrogen produced in the reaction. For cases where the metal surface is covered with a protective layer it is considered that some hydrogen ions diffuse through the layer and form hydrogen atoms beneath it. The consequence of the production of hydrogen in this location is to decrease corrosion resistance. Three types of harmful effects are illustrated. 14276

3.4.9, 4.7, 6.3.20

Studies Relating to the Reaction Between Zirconium and Water at High Temperatures. ALEXIS W. LEMMON, JR. Battelle Memorial Institute. U. S. Atomic Energy Comm. Pubn., BMI-1154, January 3, 1957, 123 pp. Available from Office of Technical Services, Washington, D. C.

Experimental studies are made of the rate of reaction between solid and mol-

ten Zircaloy and steam, spectral and total emissivity of Zircaloy and its oxide and the rate of diffusion of oxygen in Zircaloy. Theoretical and experimental studies are reported on the amount of reaction expected for a drop of molten Zircaloy falling through water. (auth)—NSA. 14080

3.5 Physical and Mechanical Effects

3.5.3

On Physical (Mechanical) Effects in Cavitation Damage. M. S. PLESSET. "Deformation and Flow of Solids" (Symposium, 1955, Madrid, International Union of Pure and Applied Mechanics), 1956, 217-235.

An experimental study in distilled water of the mechanical or metallurgical effects of the sharp pressure pulses presumably arising from the abrupt deceleration of collapsing bubbles and of the duration and magnitude of the pulses. Tests on aluminum, brass, Colmonoy, molybdenum, nickel, steel and stainless steel, Stellite, titanium and alloys and tungsten. X-ray diffraction examination to determine depth of damage and application of photoelastic techniques to determination of stresses or strains produced on a solid when cavitation bubble collapses on its surface. One conclusion is that in these experiments the primary mechanism of cavitation damage is cold work and that chemical effects are not of primary importance, though possible. —BNF. 13963

3.5.3, 1.6, 2.3.7

Cavitation in Hydrodynamics: Proceedings of a Symposium Held at the

National Physical Laboratory, September, 1955. National Physical Laboratory. Book, 1956, 470 pp. H. M. Stationery Office, London.

After the opening address, sessions on factors governing cavitation inception (5 papers); experiment techniques (4 papers); scale effect (4 papers); effects on hydrodynamic performance (3 papers); and cavitation damage (5 papers).—BNF. 12100

3.5.3, 7.1

Conditions of Intensity of Cavitation Erosion. (In Russian.) K. K. SHAL'NEV. *Bull. Acad. Sci. URSS (Izvestia Akad. Nauk SSSR)*, Technical Sciences Section, No. 1, 3-20 (1956) Jan.

Peculiarities of cavitation erosion of hydraulic equipment, particularly turbines. Effect of hydrodynamic factors. Micrographs, photographs, graphs, diagrams, tables. 83 references.—BTR. 12164

3.5.3, 3.8.2

Influence of Ultrasonics on the Anodic Dissolution of Metals. (In French.) RENE AUDUBERT AND JACQUES GUITTON. *Compt. Rend.*, 242, No. 11, 1458-1462 (1956) March 12.

The influence of cavitation produced by an ultrasonic beam, accompanied by different electrochemical reactions at the nodes and antinodes. Micrograph, graphs. 4 references.—BTR. 11984

3.5.3, 7.1

Dependence of the Cavitation Coefficient of the Hydraulic Turbine on the Soluble Air Content in Water. (In Russian.) L. S. Shmugliakov. *Energomashinstroenie*, No. 5, 11-14 (1956) May.

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Experimental data on the effect of dissolved air on the development of cavitation. Derivation of formulas relating the cavitation coefficient of a hydraulic turbine to the soluble air content of water.—BTR. 12596

3.5.3, 7.6.4

Corrosion-Abrasion Wear in Water Economizers and a Method of Protecting Them. (In Russian.) A. V. RIABCHENKO AND O. N. MURAVKIN. *Energomashinostroenie*, No. 3, 19-23 (1956) March.

Relation between wear of boiler pipes and the angle of attack and speed of flow of hot gases. Longitudinal rods welded on outside of pipe considerably lessen wear and increase service life. Diagrams, graphs, micrographs, photographs.—MR. 12588

3.5.8, 1.6, 3.5.9, 8.9.1

The Fatigue of Metals. Book, 1956, 148 pp. Institution of Metallurgists, 28 Victoria Street, London, S. W. 1.

This records the five lectures delivered at the Institution Refresher Course in October 1955: Fundamental Considerations on the Fatigue of Metals, J. Holden; Effect on Fatigue of Notches, Surface Finishes, etc., G. Forrest; Structural Aspects of Aircraft Fatigue, P. B. Walker;

Corrosion Fatigue, R. B. Waterhouse; Effect of Temperature on Fatigue Properties, P. H. Frith.—BNF. 12512

3.5.8, 6.2.3, 6.2.5

Importance of the Surface Effect on the Initiation of Fatigue Cracks. O. LISSNER. *Jernkontorets Annaler*, 140, No. 5, 360-372 (1956); *Engr Digest*, 17, No. 7, 299 (1956) July.

Fatigue tests were performed on three carbon steels and on a quenched and tempered chromium-nickel steel. Surface effect was noted, which contributes to initiation of fatigue cracks. Fatigue tests were interrupted after period corresponding to half of average life of test piece at stress applied; thin surface strip was removed by turning and test was continued. Increase in time to rupture was obtained. In carbon steels, ageing contributes to extent of effect obtained. Greatest increase in time to rupture was noted in chromium-nickel steel which showed no ageing during interval between fatigue test periods. Theory that fatigue mechanism involves plastic deformation and chemical reactions between oxygen in air and atoms in surface zone is supported.—INCO. 12497

3.5.8

Notch Sensitivity of Heat-Resistant Alloys at Elevated Temperatures. Pt. II. Analysis of Notched-Bar Rupture Life in Terms of Smooth-Bar Properties. H. R. VOORHEES AND J. W. FREEMAN. University of Michigan. U. S. Wright Air Development Center, January, 1956, 86 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 121184).

Rupture lives of smooth and notched bars were compared in tests on three heat-resistant alloys with conventional heat treatments. Additional rupture tests were run for two of the alloys using notched and smooth specimens from material cold rolled between solution and aging treatments. A definite qualitative agreement was noted between notch strengthening or weakening and the rate of experimental stress relaxation under creep conditions. A quantitative stepwise analysis was developed to compare notch rupture behavior with properties of smooth bars. 14018

3.5.8, 2.3.7

Investigation of Materials Fatigue Problems. H. N. CUMMINGS, F. B. STULEN AND W. C. SCHULTE. Curtis-Wright Corp. U. S. Wright Air Development Center Tech. Rept. 56-611, March, 1957, 208 pp.

Study of fatigue behavior of high strength steel alloys. S-N curves were obtained for SAE 4340 air-melted steel of 230 ksi UTS and vacuum melted steel of 190 ksi UTS. Several steels of 300 ksi UTS were investigated by Prot tests and S-N curves were obtained for a 4350 steel of the same UTS. Studies of relation of nonmetallic inclusions to fatigue life and strength of steels were continued and exploratory studies were made of crack initiation and propagation. Applicability of Prot method of testing to titanium alloy, aluminum alloy, aluminum-nickel bronze and beryllium-copper was also included. Tables, photos, graphs.—INCO. 14253

3.5.8, 2.3.7

Effect of Plastic Fatigue on Pressure-Vessel Materials and Design. L. F. KOOSTRA. Paper before Am. Welding Soc., Nat'l. Spr. Mtg., Philadelphia, April 8-21, 1957. *Welding J.*, 36, No. 3, 120s-130s (1957) March.

Summary of data developed through research projects at University of Illinois,

Lehigh University and Ecole Polytechnique to establish parameters governing pressure-vessel design with respect to plastic fatigue characteristics. Brief descriptions are given of tests performed at the three universities. Testing methods are evaluated for determining plastic endurance, as well as methods for establishing effective strain concentration factor of various plate surface conditions, notches, attachments and effect of welding. Conclusions on plastic fatigue properties of pressure vessel steels are grouped as: Influence of material, influence of geometry and influence of cycling conditions. Basic steels tested included ASTM A201 Grade A, ASTM A302 Grade B, A225, Fortiwell, NES 70, Navy G, T-1, 48s and J-Alloy. Tables, graphs.—INCO. 14065

3.5.8, 3.5.9

Investigation of the Behavior of Metals Under Deformation at High Temperatures. C. H. M. JENKINS AND E. A. JENKINSON. *J. Iron Steel Inst.*, 185, Pt. 1, 23-46 (1957) Jan.

Vacuum tests at 450-850 C, for times ranging from a few minutes to 13,470 hours were used to trace extent of transcrystalline and intercrystalline cracking. Minimum ductility was observed at about 550 C in about 2000 hours after which recovery was noted, a phenomenon not apparent in tests made in air. In many specimens cavities were formed which might be related to processes associated with 'dislocation' phenomena. Relationship of these cavities to further deformation of specimen and to transcrystalline and intercrystalline cracking is discussed. High local deformation appears to accelerate some of changes observed. Recrystallization, spheroidization and graphitization changes take place less rapidly than in carbon steels. Strength of carbon and molybdenum steels is compared at high temperatures. Changes in carbides had marked effect on creep resistance. Three carbides were identified; Fe₃C, Mo₂C and (Fe₃Mo₂) C₆. First named carbide is present initially in steel. The two latter appear after long exposure to temperature of 530 C and 630 C respectively and their formation removes molybdenum from ferrite, thus causing a reduction in creep strength. Tables, graphs, photomicrographs, 22 references.—INCO. 14303

3.5.8, 3.5.9

Thermal Stress Fatigue. L. F. COFFIN. General Electric Co. *Product Eng.*, 28, No. 6, 175-179 (1957) June.

Discusses origin of thermal stresses, importance of thermal stress fatigue, how materials are evaluated for thermal shock, difference between mechanical and thermal stress fatigue and design criterion required. Table presents data for computation of thermal shock parameter for molybdenum, nickel, titanium, AISI 1020, Type 410 and 347 and ceramics beryllium oxide, magnesium oxide, titanium carbide-carbon and aluminum oxide. Graphs show thermal stress fatigue and mechanical stress fatigue behavior of Type 347 showing effect of prior cold work; effect of mean temperature on thermal stress fatigue resistance of Type 347 and effect of frequency.—INCO. 14249

3.5.8, 3.5.9, 3.2.2

Mechanical Properties in Relation to Design, Requirements. C. R. SODERBERG. *Metallurgical Reviews*, 1, No. 1, 31-63 (1956).

A survey of knowledge. Failure; yielding of ductile metals; ductile failure; frac-



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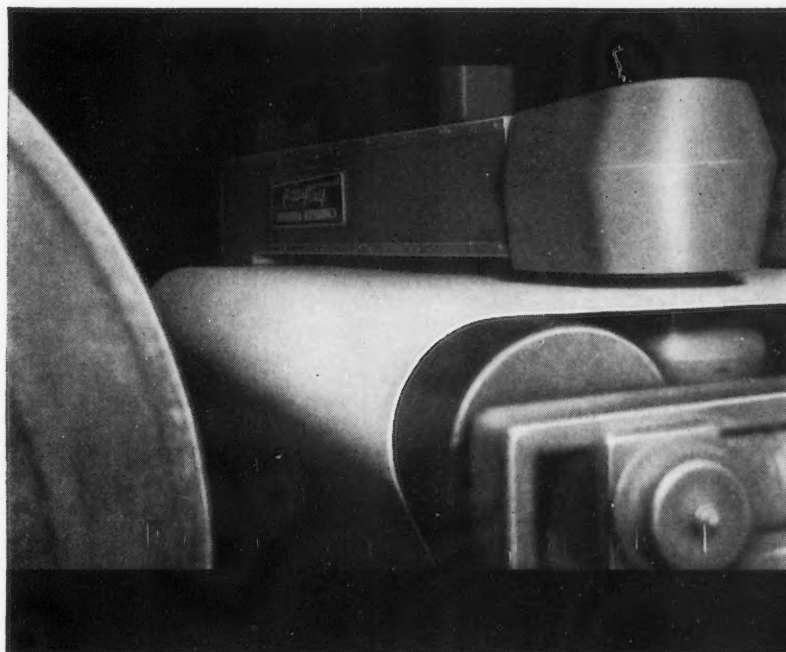
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ture; Mohr's theory of brittle fracture; fatigue; brittle fracture in large steel structures; mechanics of crack formation and propagation; brittle failures in large rotor forgings; applications of materials at high temperatures, including creep. 63 references.—BNF. 13848

3.5.8, 3.8.2

Electrochemical Elementary Processes in Stress Corrosion. (In German.) H. GERISCHER. *Z. Elektrochem.*, 61, No. 2, 276-280 (1957) Feb. 14288

An oscillograph examination of the rate of corrosion in wires of a copper-gold alloy that were subjected to a tensile load and to a change in their length.—BTR. 14288

3.5.6, 6.3.15

Thermal and Forced Diffusion of Oxygen in β -Titanium. FERNAND CLAISSE AND H. PAUL KOENIG, Dept. of Mines Labs., Quebec, Canada. *Acta Metallurgica*, 4, 650-654 (1956).

This paper reports on a study of the diffusion coefficient and mobility under the influence of an electric field, of oxygen in solid solution in β titanium. The experimental arrangement and the procedure followed is such as to yield a pair of values, one concerning diffusion and one concerning mobility in each experiment. This permits the judicious application of the Nernst-Einstein relationship relating the above-named coefficients to the charge carried by the migrating atom. A negative excess of 0.4 electron units is here found to be carried by the oxygen atoms. The exponential variation of the diffusion coefficient with temperature is best expressed by the following equation: $D = 8.3 \times 10^{-2} \exp \{-(31,200 \pm 2000)/RT\}$. The values in this equation are compared with theoretical and existing experimental values. (auth)—NSA. 13979

3.5.6, 7.4.2, 3.2.2

Failure of Steel-Admiralty Duplex Condenser Tubes by Hydrogen Penetration. H. E. HONKALA AND E. A. WRIGHT. *Corrosion*, 13, No. 8, 501t-504t (1957) Aug. 14104

The cause of rapid failure of steel-admiralty duplex condenser tubes in propane condensers was found to be due to the diffusion of atomic hydrogen through the steel tubes. These tubes were exposed to a considerable quantity of hydrogen sulfide gas and sufficient pressure was built up between the outer tube and the liner to cause the liners to collapse. These failures occurred within four weeks after the units were put into service. Tests were conducted to duplicate these failures in the laboratory. Tests also were made to study the pressure build-up rate of a "volumeless" cell in various corrosive atmospheres. 14104

3.5.8

Fatigue Strength of Specimens Containing Preformed Fatigue Cracks. N. E. FROST. *Engineer*, 203, 864-867 (1957) June 7.

Small fatigue cracks were formed in specimens of nickel-chromium steel (En. 26), 0.15 carbon steel and aluminum alloy L65, under conditions of rotating bending by applying stress above fatigue limit of material. Direct stress fatigue tests then were carried out on cracked specimens. Definite fatigue limit exists for cracked specimens and smooth S/N curve was obtained, although cracks were of unequal depth. Discussion of results in relation to work done on simi-

larly cracked specimens tested under completely reversed stress cycles is included.—INCO. 14292

3.5.8

Metal Fatigue in Theory and Design. A. J. KENNEDY. *Nature*, 178, 957-959 (1956) November 3.

A useful concise general discussion of the present state of knowledge and of future problems, against the background of the recent International Conference. —BNF. 14096

3.5.8

Deformation of Metal Surfaces Under Normal and Inclined Loads. A. W. CROOK. *Nature*, 178, 755-756 (1956) October 6.

In explanation of the fact that oxide and other protective films are less disrupted when two metal surfaces are loaded together normally than when the loading has a tangential component and the surfaces slip, it is suggested that under normal loading, even though the surfaces be permanently dented, there is a surface layer of material which is not plastically deformed, whereas if the loading is sufficiently inclined the plastic deformation extends to the surface.—BNF. 13890

3.5.8

On the Problem of Stress Corrosion of Non-Ferrous Alloys. (In German.) H. VOSSKUHLER. *Metall*, 11, No. 3, 193-196 (1957) March.

An electrochemical theory of stress corrosion in aluminum alloys is presented. It is pointed out that stress corrosion can only develop if both intercrystalline and transcrystalline points of rupture are anodic with respect to the rest of the crystal surface. The process, leading to a rupture caused by stress corrosion, is said to proceed in two stages. During the preparatory stage, which, generally, extends over a long time span, the corrosion-process is predominant. Once, at some sensitive spot, the initial attack has progressed far enough to disturb the stress-deformation equilibrium, a creep process sets in, which disrupts the surface layer of the cavity formed by corrosion, thus exposing the metal of less noble potential to an accelerated attack. This cycle, which consists in creep, thus increased corrosion again causing a higher rate of creep, and so on, leads to an autocatalytic acceleration of the process and finally, to the rupture of the metal.—ALL. 13865

3.5.8

Interrelation of Fatigue Cracking Damping and Notch Sensitivity. L. J. DEMAR. University of Minnesota. U. S. Wright Air Development Center, March, 1957, 164 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 131025).

This volume is the fourth in a series dealing with the general subject of fatigue cracking. Results of previous studies are summarized, including observations on the changes in damping as a function of frequency, stress level and stress history at a given stress level. Relations among damping elasticity, fatigue and notch sensitivity of metallic materials are discussed. The body of the report contains results of numerous fatigue tests performed on a variety of metallic materials in which observations were made of the changes in damping and stiffness properties of the specimens and of the development of fatigue macro-

cracks. These test results are discussed in relation to previous investigations and new relations between dynamic properties of materials are evolved. Used for the investigations were alloy N-155, a high-carbon steel in two conditions of heat treatment, gray iron, aluminum alloy, J-1 magnesium alloy and SAE 1020 steel. 14259

3.5.9, 3.5.9, 6.3.15

A Study of the Process of High Temperature Oxidation of Metallic Titanium in Water Vapor. (In Russian.) G. P. LUCHKIN AND G. G. IL'IN. *Fizika Metallov i Metallovedenie*, 2, No. 3, 521-523 (1956).

Higher oxidizability is explained by the structural peculiarities of scale formation, which accounts for a more intensive diffusion of oxygen in the metal than in the case of oxidation in the open air.—BTR. 12824

3.5.9

High Temperature Materials: A Review. E. A. BRANDES. *Product Eng.*, 27, No. 9, 186-190 (1956) Sept.

Properties required in high temperature materials and general discussion of methods of their evaluation (creep, scaling, fatigue, thermal shock tests). Properties and applications of available materials; ferritic and austenitic steels, cobalt alloys, nickel (Nimonic) alloys. Experimental materials: chromium and molybdenum alloys, ceramics, titanium- and chromium-carbides bonded with cobalt or nickel.—BNF. 13034

3.5.9

How 7 Non-Ferrous Metals Perform at Low Temperatures. T. GELA, W. J. LEPKOWSKI AND H. M. GADE. *Materials & Methods*, 44, No. 3, 116-120 (1956) Sept.

Copper-beryllium, phosphor-bronze, silver solder, molybdenum, tungsten, tantalum, Nilvar (iron-36% nickel). Tables of mechanical properties (tensile strength, yield strength, elongation, Rockwell hardness, modulus of elasticity, fatigue strength, endurance ratio, tension impact properties) at 27 C and -73 C; discussion of variations in these properties; graphs of fatigue properties for molybdenum, tantalum and Nilvar.—BNF. 12793

3.5.8, 3.7.4, 4.2.1

The Mechanical and Metallurgical Factors in the Corrosion of Metals in a Humid Atmosphere: Relation Between Intergranular Corrosion and Structure of Grain Boundaries. (In French.) P. LACOMBE. *Metaux: Corrosion-Industries*, 31, No. 373, 337-354 (1956) Sept.

Intergranular corrosion of brasses or "season cracking"; intergranular corrosion of stainless steels; stress-corrosion of aluminum-magnesium alloys of high magnesium content. Grain boundary structure. Brittleness, loss of cohesion and critical intergranular corrosion in stress-corrosion tests.—BNF. 13165

3.5.8, 6.2.3, 2.3.7

Observations on the Process of Intergranular Stress Crack Corrosion of Soft Plain Carbon Steels. (In German.) WILHELM RADEKER AND HUBERT GRAFEN. *Stahl und Eisen*, 76, No. 24, 1616-1628 (1956) Nov. 29.

Report from the Research Institute of the Phoenix-Rheinrohr AG at Mülheim (Ruhr) and from the Materials Testing Laboratory of the Badische Anilin- und Sodafabrik at Ludwigshafen. Report No. 1055 of the Committee for Materi-

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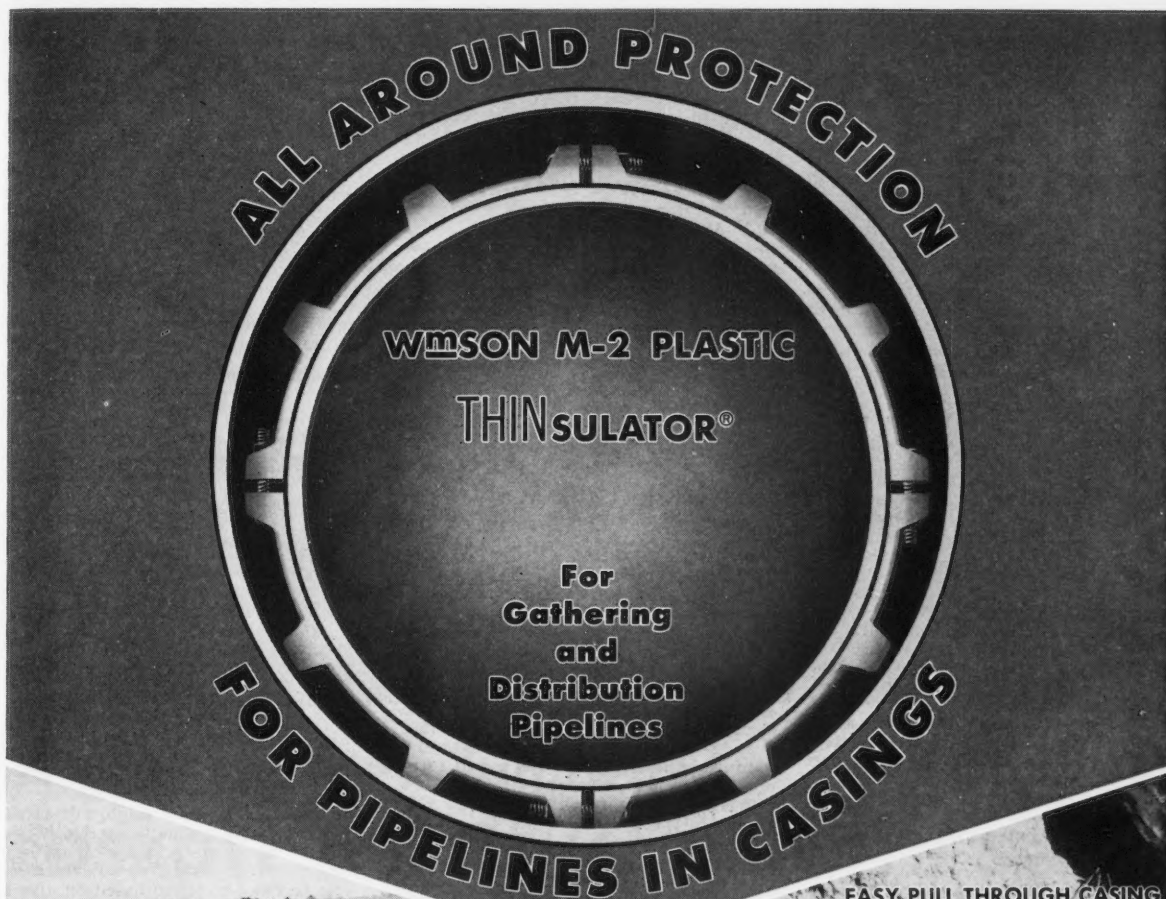
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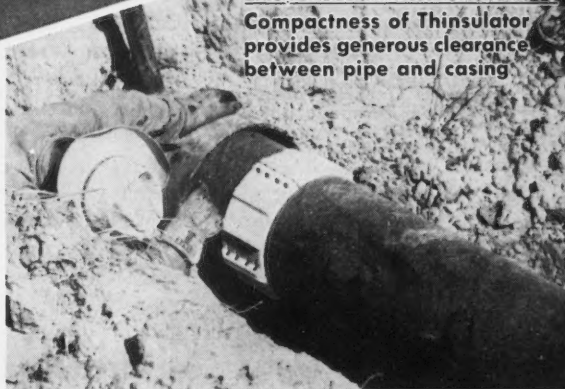
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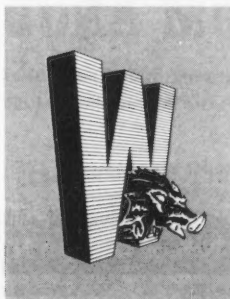
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als of the Verein Deutscher Eisenhüttenleute. The ratio between stress and life as dependent on the yield point of the steel. Effect of cold deformation. Behavior of pure iron. Effect of tempering time and temperature with steels treated by aluminum. Comparison between the Jones test and the tensile test in caustic solutions. Aluminum content required of the steel. Effect of ageing. Propagation rate of the cracks. Chemical effect of the attacking agents: nitrate concentration, pH-value, effect of manganese salts and halides, magnesium salts in the presence of abrupt temperature changes. Cracking caused by caustic soda solutions. Attempt of interpreting the process of stress corrosion cracking.—SE. 13301

3.5.8

Tensile Fracture of Ductile Metals. H. H. BLEAKNEY. *Can. Metals*, 20, No. 2, 60, 62-64 (1957) Feb.

Discussion of apparent discrepancy between theoretical cohesive strengths of metals and apparent strengths observed in tension tests. Evidence presented is confined to shear fractures of ductile metals. Tension tests of commercial purity aluminum, high purity aluminum and heat treated mild steel revealed 3 modes of fracture. When test piece shows 100% reduction in area before rupture, both reduced cross-sectional area and load at instant of rupture approach zero. Where fracture is result of fissure across axis and its propagation, either slowly or rapidly, fracture stress may be taken as load divided by cross sectional area at instant of formation of fissure, if stress were uniformly distributed. However, since stress is not uniformly distributed and there is no way of ascertaining exact value of load at which fissure is first formed, it is evident that no discrepancy has really been observed between true cohesive strength and actual breaking strength.—INCO. 13755

3.5.9

The Process of Oxidizing Metals and Alloys at High Temperatures. (In French.) J. BENARD. *Metaux: Corrosion-*

Industries, 31, No. 371/372, 306-310 (1956) July-August.

Factors influencing oxidizability of metals and alloys as influenced by the oxide layer between metal and oxygen, nature of component metals, impurities and surface temperature.—MR. 13514

5. PREVENTIVE MEASURES

5.3 Metallic Coatings

5.3.2

Cathodic Protection by Sprayed Aluminum Coatings. W. F. HIGGINS. *Chemistry and Industry*, No. 18, 382-383 (1956) May. 12.

A letter. The mechanism of the protection afforded to steel by sprayed aluminum coatings is discussed with special reference to the opinion that cathodic protection is not involved.—MA. 13238

5.3.2

Properties of Flame-Sprayed Zinc Coatings. (In German.) E. GEBBARDT AND H. D. SEGHEZZI. *Z. Ver. Deut. Ing.*, 98, No. 2, 41-45 (1956).

A detailed account of an investigation into the mechanical properties of sprayed zinc coatings. Zinc, in the form of wire or powder, is melted in an oxyacetylene flame and sprayed by a jet of compressed air. The tensile strength, hardness, impact bending strength, compressive strength, adhesive strength and electrical conductivity of the resulting coating are tabulated in relation to the nature of the flame and the initial form of the zinc. The results obtained are discussed very fully with particular reference to the preparation of the underlying metal surface. Coatings applied on surfaces roughened by shot- and sand-blasting are illustrated.—ZDA. 13211

5.3.2

The Structure of Electrodeposited Metals. R. WEILL AND H. J. READ. *Metal Finishing*, 54, No. 1, 56-59 (1956) Jan.

The surface structure of several electrodeposited metals, including zinc, cadmium, nickel and cobalt, have been

classified and found to be reproducible, indicating that they are a function of the bath and plating conditions. A theory is proposed for the formation of the various structural types, based on a consideration of the lattice structure of the plated metal and the amount of growth-impending material in the cathode film. It is suggested that the brightness of the deposits is determined by the grain size and platelet orientation in grains of any size. Electron micrographs show the structures obtained from acid and cyanide baths of zinc and cadmium.—ZDA. 12656

5.4 Non-Metallic

Coatings and Paints

5.4.5

Maintenance Painting Procedures. A. L. KINMEL. *J. Am. Water Works Assoc.*, 48, 91-94 (1956); *J. Applied Chem. Absts.*, 6, Pt. 8, ii-165 (1956).

The main fundamentals for achieving a satisfactory painting result are discussed in sections dealing with surface preparation, primers for steel, concrete, masonry, plaster and wood and finish coats. Practical hints are given.—RPI. 13162

5.4.5

Paint Adhesion Under Moist Conditions. D. M. JAMES. *J. Oil Colour Chemists' Assoc.*, 39, No. 1, 39-66 (1956) Jan.

Fresh water was found to weaken the adhesion of finishing coats to primers more than sea water. The nature of the primer, particularly its medium was found to be the most important factor affecting adhesion. The general adhesion of paints to primers based on oil was good, to those based on oleoresinous media bad and to those based on alkyds and epoxide esters variable. Four paints containing zinc chrome were among those tested.—ZDA. 13157

5.4.5

Rust-Preventing Coatings. Pt. I. (In German.) K. A. VAN OETEREN-PANHAUSER. *Metalloberfläche*, 10, No. 6, 167-173 (1956) June.

General survey of rust prevention problems. Properties of coatings, mechanism of their action, need for multiple coats, methods of application.—MR. 12636

5.4.5

Leaf-Free Aluminum Pigments: Polychrome and Hammer Finish. W. F. TORREYSON, JR. AND K. E. LUYK. *Paint, Oil, Chem. Rev.*, 119, No. 15, 8-11 (1956) July 26.

The choice of aluminum pigment is an important factor in obtaining the desired properties in a metallic paint, but it is not the only consideration in formulating either a polychrome or hammer finish. The proper selection and combination of resins, solvents and color pigments is also essential. Factors in formulation, techniques of application, properties and possible defects for polychrome and hammer finishes.—RAD. 12611

5.9 Surface Treatment

5.9.2

Standards for Steel pickling and Pre-Paint Treatments. I. GELD, M. ACAMPORA AND W. L. MILLER. *Orig. Finishing*, 17, No. 8, 14-15 (1956).

The preparation and preservation of a set of panels representing different stand-

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A LEADER IN THE FIELD OF INDUSTRIAL COATINGS FOR CORROSION CONTROL.

ards of surface preparation by pickling are described.—RPI. 13204

5.9.2

Cleanability and Oil-Spreading Rates. A. L. BISIO, H. B. LINFORD AND E. B. SAUBESTRE. *Ind. & Eng. Chem.*, 48, No. 4, 798-801 (1956).

A soak cleaner and an electrolytic cleaner were used to clean steel or copper surfaces soiled with a variety of oily materials including neat's foot oil, butyric acid, cutting oil, lard oil, mineral oil, mineral oil/nitrobenzene, nitrobenzene, oleic acid and motor oil. The spreading rate of the oils appeared to be a rough measure of the bonding ex-

sisting between oil and metal and was thus related to the ease of cleaning.—RPI. 12773

5.9.2, 3.3.2, 8.9.5

Chemical Cleaning for Firemain Systems. M. D. STARR. *Bureau of Ships J.*, 5, No. 1, 20-23 (1956) May.

Discusses fouling of marine firemain systems by scale and marine growth (serpulid worms, barnacles, mussels, oysters) and chemical cleaning with hydrochloric acid. Water flow is restricted up to 90 percent in ferrous-metal firemain and to lesser degree in copper-nickel piping. Serpulid worms settle quickly on toxic surfaces which may explain fouling of copper-nickel piping. Inhibitors are added to acid to slow down acid attack. Acid is maintained at

120-150 F. in system. Summary of cleaning procedure, published in Bur. of Ships Military Specification MIL-C-18159, October 29, 1954, is given.—INCO. 13415

5.9.2, 6.2.5

Chemical Polishing of V2A Steel Using Gaseous Media. G. SCHMID, E. MAURER AND H. STEINHAUSEN. *Metall-berflache*, 10, 289-295 (1956).

Details of apparatus and technique developed for chemical polishing of Krupp V2A 18/9.5 chromium-nickel steel. Procedure adopted is to expose steel to gaseous mixture of steam, hydrochloric acid and nitrogen peroxide. Optimum conditions are detailed.—INCO. 13378

5.9.2, 6.3.19, 6.3.2

Chemical Polishing of Pure Zinc (and Cadmium). J. J. GILMAN AND V. J. DE CARLO. *Trans. Am. Inst. Mining Met. Engrs.*, 206, No. 5, 511-512 (1956).

The composition of the customary solutions used for the chemical polishing of zinc are noted. For the best results the following modification of the nitric acid polish is recommended: a mixture of equal parts of nitric acid (conc.), ethyl alcohol, and hydrogen peroxide (30%); it must be freshly prepared each day. Polishing occurs within seconds after immersion, but ~2 minutes is needed to obtain the highest lustre at room temperature. The polished surface is stable towards rapid oxidation up to ~350 C in air or in a salt-bath of mixed potassium and sodium nitrates. For pure cadmium, a successful mixture consists of nitric acid (conc.) 1, ethyl alcohol 2, and hydrogen peroxide (30%) 2 parts. 4 references.—MA 13219

6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.2, 2.3.7

The Impact Properties of Ferritic Nodular Irons in the Ductile and Brittle Condition, Using Standard and BCIRA Impact Specimens: BCIRA Res. Rept. No. 448. G. N. J. GILBERT. *J. Res. and Development, Brit. Cast Iron Res. Assoc.*, 6, No. 9, 422-429 (1956) Dec.

Impact values obtained with standard Charpy and Izod specimens are compared with those obtained with BCIRA ½-inch V-notched specimens used for research purposes and BCIRA ⅜-inch square unnotched specimen. BCIRA V-notched specimen gives wider range of impact values than standard V-notched specimen but similar transition curves are obtained with both types. Materials tested were three nodular irons treated with nickel-magnesium-cerium alloy and inoculated with ferro-silicon; chemical compositions were varied to produce completely ductile, mixed ductile and brittle and completely brittle fractures. A ferritic flake graphite cast iron was also tested. Bend test frequently used for testing ductibility of malleable irons is shown to be a less severe test for detecting brittleness than V-notched im-

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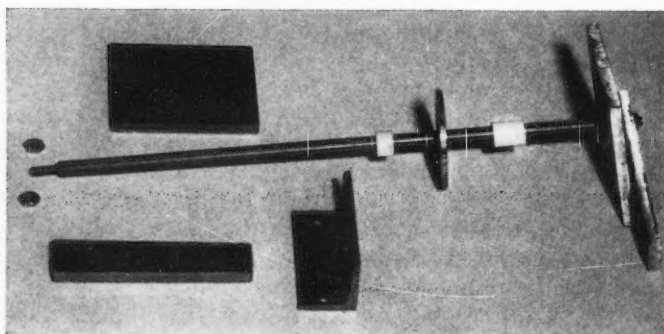
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compact test. Transition curves are given for 0:58 nickel nodular iron. Photographs of specimens.—INCO. 13241

6.2.2, 2.4.2

On the Corrosion of Malleable Iron. (In English.) N. TSUTSUMI. *Repts. Castings Res. Lab., Waseda University*, No. 7, 19-23 (1956) Oct.

To compare corrosion resistant properties of black heart malleable iron, steel and cast iron, total immersion tests were conducted in 2 hydrochloric acid, 0.5 salt water, 5 acetic acid and 10 nitric acid and electro-potential difference measurements were made in 2, 0.5 and 0.1 hydrochloric acid and 0.5 salt water. Results are summarized in graphs. Photograph shows merry-go-round type corrosion testing apparatus.—INCO. 13410

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.5, 5.9.4

Space Charge in Formation of Anodic Oxide Films (on Niobium). L. YOUNG. *Acta Metallurgica*, 4, No. 1, 100-101 (1956).

A letter. Impedance measurements have been made on oxide films on niobium which indicate that a space charge is present during formation of the film and decreases with increasing current density. This observation supports Dewald's theory [*ibid.*, 2, 340 (1954)]; *J. Electrochem. Soc.*, 102, 1 (1955)] of anomalies observed during the formation of anodic films on tantalum. 7 references.—MA. 12662

6.3.5, 6.3.13, 4.3.4

Action of Mixtures of Hydrofluoric Acid and Hydrogen Peroxide on the Metals Niobium and Tantalum. G. I. BARANNIKOV. *J. Applied Chem., USSR* (Zhur. Priklad. Khim.), 29, No. 8, 1282-1287 (1956).

Solubility and rate data are reported. 2 tables, 1 figure, 10 references.—ATS. Translation available from: Associated Technical Services, P. O. Box 271, East Orange, New Jersey. 12768

6.3.6

Finishing Methods for Aluminium Bronze Gravity Die Castings. A. C. STREET. *Product Finishing*, 9, No. 4, 48-53 (1956) April.

Composition, mechanical properties, casting technique. Though corrosion resistance is good, finishing process may be required to impart resistance under some conditions, or for decorative or matching effects. Cleaning treatments, painting and enamelling, "bronzing," electroplating. Importance of proper design of die-castings.—BNF. 12604

6.3.6, 2.2.2

Effect of Natural Atmospheres on Copper Alloys: 20-Year Test. A. W. TRACY. Paper before ASTM, 58th Ann. Mtg., Symp. on Atmospheric Corrosion of Non-Ferrous Metals, Atlantic City, June 29, 1955. Am. Soc. Testing Materials Special Technical Publication No. 175, 1956, 67-76.

Discusses corrosion resistance of 11 copper alloys exposed to industrial, marine and rural atmospheres for twenty years. Evaluation is based on weight-loss measurements and changes in mechanical properties of sheet specimens. Metals tested were electrolytic tough-pitch copper, phosphorous-copper, silicon bronze, phosphorus-bronze, aluminum bronze, high-tensile brass, red brass,

70-30 copper-zinc brass, Admiralty metal, 75 copper-20 nickel-5 zinc and 70 copper-29 nickel-1 tin. Resistance of copper alloys was found to be largely a function of type of corrosion product formed. Some observations on dezincification and stress-corrosion cracking were made. Tables, graphs.—INCO. 12625

6.3.6, 2.2.2

The Atmospheric Corrosion of Copper: Results of 20-Year Tests. D. H. THOMPSON, A. W. TRACY AND J. R. FREEMAN, JR. Paper before ASTM, 58th Ann. Mtg., Symp. on Atmospheric Corrosion of Non-Ferrous Metals, Atlantic City, June 29, 1955. Am. Soc. Testing Materials Special Technical Publication No. 175, 1956, 77-87; disc., 88.

Eleven brands of copper in sheet and wire form were exposed to normal industrial, accelerated industrial, marine and rural atmospheres in Connecticut. Effect of corrosion was evaluated by weight loss, loss in strength and gain in electrical resistance. Mean corrosion rate is 50×10^{-6} inch per year. Corrosion products were analyzed. Purest copper corroded the least while those with arsenic corroded most. Tables.—INCO. 12609

6.3.6, 3.2.2

Intergranular Brittleness of Single-Phase Copper-Antimony Alloys. L. M. T. HOPKINS. *J. Inst. Metals*, 84, No. 5, 102-108 (1956) Jan.—BNF. 13244

6.3.6, 3.2.3

New Researches on the Initial Oxide Formation in Slow Copper Oxidation. (In French.) FINN GRONLUND. *J. Chim. Phys.*, 53, No. 7/8, 660-666 (1956) July-August.

The conditions of initial formation of copper oxide on particular points of metallic surfaces were quantitatively studied in relation to its mechanism.—MR. 13232

6.3.6, 3.2.3, 3.8.4

The Effect of Sulphur Dioxide on the Oxidation of Copper. T. MILLS AND U. R. EVANS. *J. Chem. Soc.*, 1956, 2182-2196, July.

The effects of small additions of sul-

fur dioxides on the oxidation of copper were studied at temperatures from 88 to 172 degrees. The growth laws observed in pure oxygen in this temperature range agreed with observations by recent workers and were interpreted in terms of a mechanism which accounted for the transition from logarithmic growth at low temperatures to parabolic growth at high temperatures by means of a single theory. Sulfur dioxide accelerated the oxidation of copper, although it did not alter the mechanism of the film-growth laws. It also caused a controlled growth of cuprous sulfate in the film by a secondary reaction; the amount of sulfate was a linear function of the cuprous oxide in the film. 13299

6.3.6, 3.2.3, 3.8.4

Cuprous Oxide and Zinc Oxide Single Crystal Formation by Selective Oxidation of an α -Brass Film, Prepared by Vacuum Evaporation. (In French.) N. TAKAHASHI AND J. J. TRILLAT. *Acta Metallurgica*, 4, No. 2, 201-205 (1956) March.

Thin films were prepared under vacuum by successive deposition of copper and zinc, oxidized by heating in the specimen chamber of the electron diffraction unit and studied with respect to processes of selective oxidation. Diagrams, diffractograms. 10 references.—BTR. 12603

6.3.6, 3.5.8

Combined Stress Creep Fracture of a Commercial Copper at 250° C. A. E. JOHNSON, J. HENDERSON AND V. D. MATHUR. *Engineer*, 202, 261-265, 299-301 (1956) August 24, August 31.

The tertiary creep characteristics of a commercially pure copper under pure tension, pure torsion, pure compression and combined tension and torsion were studied. The fractures were intercrystalline. The maximum tensile principal stress was most important in the tertiary stage, presumably by propagating cracks instituted in the primary stage.—BNF. 13154

6.3.6, 3.5.9, 1.6

Elevated Temperature Properties of Coppers and Copper-Base Alloys. CLAIRE

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UPTHEGROVE AND HENRY L. BURGHOFF. ASTM Special Technical Publication No. 181, April, 1956, 244 pp. Available from: American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pennsylvania.

Graphed and tabulated data on the elevated temperature properties of wrought coppers and cast and wrought alloys of copper. Included are modulus of elasticity, tensile strength, yield strength, reduction of area, elongation, stress for creep rates at three values and stress for rupture in four periods from 100 to 100,000 hr. Temperatures are in range 300-900 F for most tests while rupture tests were made at 300-400 F.

This is one of the reports prepared under auspices of the Data and Publications Panel of the ASTM-ASME Joint Committee on the Effect of Temperature on the Properties of Metals.

12601

6.3.6, 3.8.4

The Composition and Reduction of Oxide Films on Copper. R. F. TYLECOTE. *Metallurgia*, 53, No. 319, 191-197 (1956) May.

Reduction rate of cupric and cuprous oxide to copper; mechanism of oxidation and reduction. Photographs, graphs, tables. 12 references.—BTR.

12628

6.3.6, 4.4.6, 3.2.2

Combating Corrosion Cracking of Brass Liquid Fuel Collectors. A. V. SHREIDER. *J. Applied Chem., USSR* (Zhur. Priklad. Khim.), 29, No. 7, 1044-1056 (1956).

Tubes operating under pressure (of 45 atm.) and exposed to kerosene (0.13% sulfide sulfur) and vibrations experience corrosion cracking attributable to presence of small amounts of ammonia in air (to 0.0001%). 1 table, 7 figures, 28 references.—ATS. Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.

12614

6.4 Non-Ferrous Metals and Alloys—Light

6.4.2

Problems Associated with the Production and Use of Wrought Aluminium Alloys. G. FORREST AND K. GUNN. *J. Roy. Aeronaut. Soc.*, 60, No. 550, 635-658 (1956) Oct.

The authors have attempted to survey the problems of production and use of aluminum alloys as they affect the user. The production of aluminum aircraft alloy is described in detail beginning with remelting and alloying, casting, mechanical working or forming, heat treatment, subsequent operations and inspection, tensile properties, fatigue properties and stress corrosion as affected by production variables are discussed. Finally the processes of bending and forming are treated. Twenty-four references are appended.

13199

6.4.2

Properties, Technology and Uses of Near-Eutectic Aluminum-Silicon Alloy. (In Italian.) Istituto Sperimentale dei Metalli Leggeri. *Alluminio*, 25, No. 3, 149-156 (1956) March.

Physical and mechanical properties, heat treatment, corrosion resistance, microstructure and uses of cast aluminum-12% silicon and aluminum-9% magnesium.—BNF.

12756

6.4.2, 2.2.2

Resistance of Aluminum-Base Alloys to 20-Year Atmospheric Exposure. C. J. WALTON AND WM. KING. Paper before

ASTM, 58th Ann. Mtg., Symp. on Atmospheric Corrosion of Non-Ferrous Metals, Atlantic City, June 29, 1955. Am. Soc. Testing Materials Special Technical Publication No. 175, 1956, 21-44; disc., 45-46.

Discussion of 20-year atmospheric weathering data obtained on wrought aluminum-base alloys included in ASTM outdoor exposure investigations. Pertinent data obtained after 1, 3, 6, 10 and 20 years are tabulated and arranged graphically to illustrate such characteristics as effect of natural aging on tensile strength of specimens stored indoors for twenty years, rating of corrosivity of seven atmospheric conditions employed and weathering rate of five aluminum alloys. These data are correlated with data obtained by Alcoa on tests with newer aluminum alloys and aluminum-clad products.—INCO.

12637

6.6 Non-Metallic Materials

6.6.8, 7.2, 2.3.1

Strength and Service Characteristics of Glass Reinforced Epoxy Oilfield Pipe. H. D. BOGGS. *Corrosion*, 13, No. 9, 117-118, 120 (1957) Sept.

Important considerations in evaluating the characteristics of reinforced plastic pipe are reviewed. Fifteen tests used by the writer's company in checking strength and reliability of its product are listed. Resistance of epoxy-glass reinforced plastic pipe versus 26 acids, four alkalis, four gases, 15 salts, 11 solvents and 10 industrial fluids is tabulated. Some data are given on experience, particularly in oil-field service.

14178

6.6.8, 8.8.1

Properties and Performance of Reinforced Polyester Plastics in the Chemical Industry. R. E. GACKENBACH AND D. G. ESTEV. *Corrosion*, 13, No. 8, 546t-552t (1957) August.

The use of reinforced polyester resins as a material of construction in the chemical industry is relatively new and is one which warrants periodic review. This paper discusses some of the basic properties of polyesters which must be considered by designers and fabricators and gives some examples of actual field installations. The use of reinforced polyester resins for alum evaporators, stacks, dryer trays, filter troughs and filter press plates and frames is discussed in detail. This detailed information is given so that other end users may evaluate this material for their specific requirements.

14042

6.6.6

Recent Developments in the Application of Transition Metal Borides. ARNOLD BLUM AND WILLIAM IVANICK. Boronite Corp., Yonkers. *Powder Met. Bull.*, 7, 75-78 (1956) April.

Some of the transition metal borides (chromium boride, zirconium boride, and molybdenum boride) have been described which are now being used widely for their outstanding liquid metal corrosion resistance, high-temperature stability in vacuum and superior oxidation resistance at high temperatures.—NSA.

13504

7. EQUIPMENT

7.1 Engines, Bearings and Turbines

7.1

Performance of 110-Millimeter-Bore M-1 Tool Steel Ball Bearings at High

Speeds, Loads, and Temperatures. W. J. ANDERSON. Lewis Flight Propulsion Lab. U. S. Nat'l. Advisory Comm. for Aeronautics, Tech. Note No. 3892, January, 1957, 38 pp.

Eleven bearings lubricated with synthetic lubricant of diester type were run at speeds up to 14,000 rpm at mean outer-race temperatures up to 678 F. Cage materials were iron-silicon bronze, silver-plated iron-silicon bronze and cast Inconel. Eight bearings failed in fatigue indicating that fatigue life of M-1 bearings might be shorter than life of SAE 52100 bearings lubricated with mineral oil. Fatigue failures were characterized by deep fissures running perpendicular to surface rather than normally shallow, horizontal pattern. Under conditions of continuous oil flow, iron-silicon bronze was best cage material tested. Silver plate showed tendency to blister. Cast Inconel with preformed surface film of nickel oxide is not satisfactory as cage material for bearing operating at high speed and temperatures below 600 F. Tables, graphs.—INCO.

13734

7.1

Bearings for Tough Jobs. *Steel*, 140, No. 14, 114-116, 118 (1957) April 8.

In three parts: Difficult Environments, W. BLINDER; High Temperatures, G. H. RALEY; Nuclear Reactors, A. BOYD.

Materials most generally used for ball bearings are high carbon-high chromium steels. 440C stainless steel is used for mildly corrosive conditions and AISI 5120 for bearings which need a ductile core for toughness or high impact strength. Separator, or cage materials are generally 1010 steel or 430 stainless of stamped-ball controlled design for low or normal speed conditions. Corrosion resistant cobalt, chromium-base, nickel-base and copper-base alloys are used for operations in pressurized water at temperatures up to 1600 F and in corrosive gases. Bearing materials have certain limitations of operating temperatures.—INCO.

14160

7.1, 6.3.15

The selection of Materials for High-Temperature Applications in Aircraft Gas Turbines. Battelle Memorial Institute, Titanium Metallurgy Lab. Report No. 50, August 17, 1956, 35 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 121619).

Survey of major gas-turbine manufacturers to determine applicability of titanium in gas turbines and criteria whereby materials are selected. Ultimate tensile strength, yield strength, stress-rupture properties and fatigue strength of three commercial titanium alloys and one experimental alloy are compared on a strength/density basis with similar properties for other metals including 310 stainless, AM 350, Lapelloy, 4340 steel, A-286 and Inconel X. Other properties considered are modulus of elasticity, thermal stability and notch sensitivity. Temperature range for superior performance of titanium over other metals is identified. Discussion is given on current applications of titanium in gas turbines and possible influence of future trends in gas-turbine development. 36 references, graphs, tables.—INCO.

13949

7.1

Special Materials for Unusual Ball Bearing Applications. W. BLINDER. Gen. Motors Corp. *Gen. Motors Eng. J.*, 4, No.

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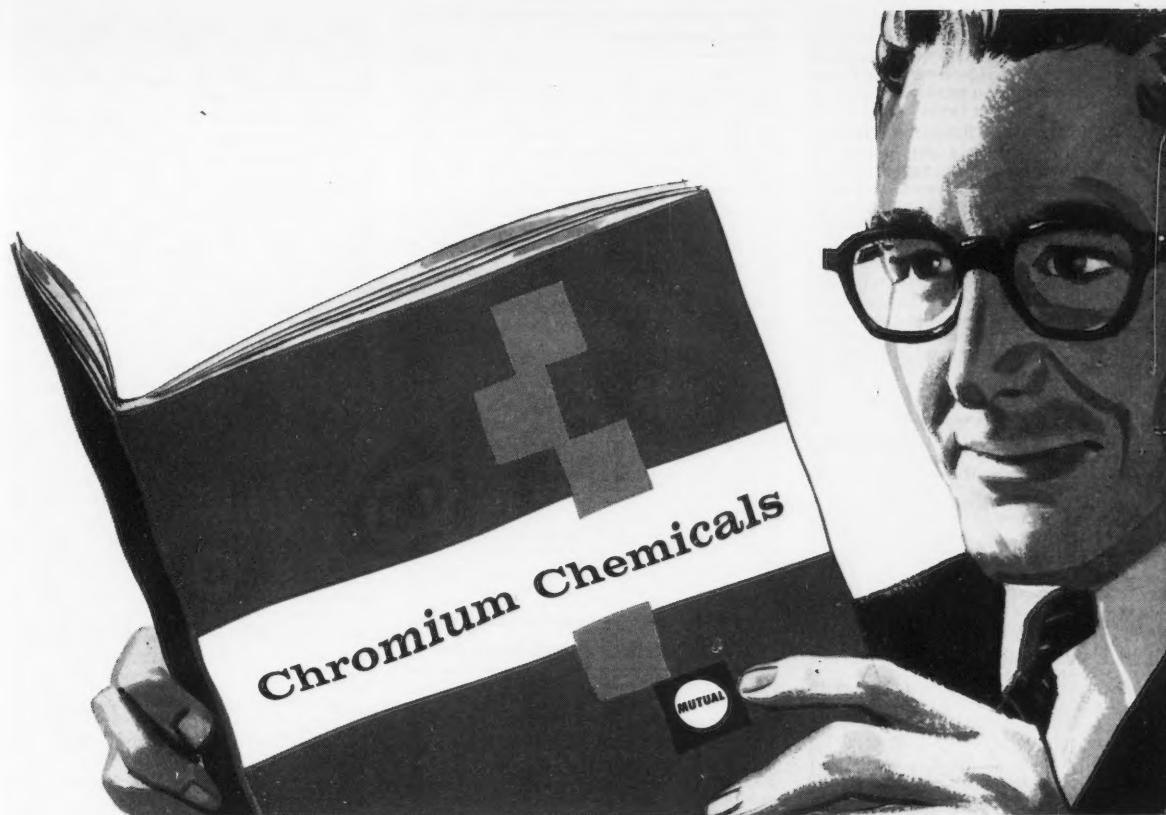
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1, 42-46 (1957) Jan.-Feb.

Reviews standard operating conditions and standard materials for ball bearings, methods used at GM's New Departure Division to evaluate materials (gall or compatibility, hot hardness and creep strength, bearing performance, fatigue and wear) and materials best suited for high-temperature, non-magnetic and corrosion-resistant applications. Tables summarize properties and ratings for ball bearing materials (including AISI 52100 and 51100 steels, type 440C, vacuum- and air-melted high-speed tool steels, beryllium-copper, tungsten carbide, cobalt- and chromium-base alloys) and for separator materials (including Type 430, 17-4 PH, S-Monel, silver plate, iron-silicon-bronze and 1010 steel).—INCO. 14239

7.1

Application of Research to the Design of Marine Steam Turbines. T. W. F. BROWN. *Trans. Inst. Marine Engrs.*, 69, 65-93; disc., 94-102 (1957) March.

Review of Pametrada work includes data on: Relative salt-spray corrosion of possible blade materials (Monel, K Monel, 18/8, 18/2 and 13-chromium steels, 13, 17 and 20-chromium stainless steels and aluminum bronze K Monel had lowest weight losses); susceptibility of unstressed turbine-blade alloys (Monel, Hecla A.T.C., stainless iron, molybdenum-bearing stainless iron and mild steel) to attack by molten brazing metals; gear failures (tooth breakage in unspecified alloy steel pinion at 490 K; scuffing in alloy steel pinion at 378 K; seizing of bolts in ferritic steels at 800-1050 F and stresses up to 10,000 psi (use of molybdenum disulfide grease or sulfurization gave reasonable protection); glands (use of leaded nickel bronze in place of brass gave less pick-up on rotor but combination Nimonic/F.D.P., sometimes used in gas turbines, gave lower energy losses).—INCO. 14057

7.2 Valves, Pipes and Meters

7.2, 7.1, 2.3.1, 1.6

A Symposium on Internal Combustion Engine Valves. Book, 1957, 216 pp. Published by Valve Division, Thompson Products, Inc., Cleveland, Ohio.

Collection of articles, reprinted from various sources, on subject of internal combustion engine valves. Includes: Metallurgical Consideration for Automotive Exhaust Valves, M. J. Tauschek; Corrosion of Gasoline Engine Exhaust Valve Steels, C. H. Allen and M. J. Tauschek; Laboratory Testing Techniques, M. J. Tauschek and J. C. Sawyer; Design Characteristics of Valve Rotators, W. S. Gleason; Basic Factors Affecting Engine Valves, M. J. Tauschek; Engineering of the Poppet Valve, J. A. Newton; Valve Gear Fundamentals for the Large Engine Designer, J. A. Newton and C. H. Allen; Factors Affecting Diesel Exhaust Valve Life, J. A. Newton, J. L. Palmer and V. C. Reddy; Valve Seat Distortion, M. J. Tauschek and J. A. Newton; Considerations for Commercial Valve Maintenance, J. A. Newton and N. Hoertz; Some Aspects of Valve Burning and Sticking, J. A. Newton; Production Surfacing of Aluminized Engine Valves, J. A. Newton and M. D. Braid; Cam Design as Related to Valve Train Dynamics, T. R. Thoren, H. H. Engemann and D. A. Stoddart; Polydyne Cam Design, D. A. Stoddart. 14167

7.5 Containers

7.5.5, 6.6.8

Service Experience of Glass-Reinforced Plastic Tanks. Status Report of NACE Technical Unit Committee T-1J on Oil Field Structural Plastics (W. B. SANFORD, Chairman). *Corrosion*, 13, No. 7, 459t-460t (1957) July.

Previous reports had indicated that a glass mat reinforced polyester 250-barrel oil field storage tank showed little increase in circumferential measurement. It was found, however, that this tank suffered a tension failure at one of its staves and had to be scrapped after only 46 months' service.

Data are given to show the results of circumferential measurements made on a glass-epoxy 250-barrel oil field stock tank in both the full and the empty condition over one winter and three summers. Results also are reported of circumferential measurements made on a full 500-barrel wash tank during two summers. The average increase in circumference between the first and second summer for the 500-barrel tank was 0.020 as compared to 0.006-foot for the 250-barrel tank. 13873

7.6 Unit Process Equipment

7.6.4, 4.2.3

Chemical Processes in the Combustion Chambers of Slagging Boilers. (In German.) K. WICKERT. *Brennstoff-Wärme-Kraft*, 9, 105-118 (1957) March.

Concludes that corrosion in slagging chambers can be prevented only by purposive construction of the burners.—BTR. 14130

7.6.4, 4.6.2

Corrosion in Scotch Marine Boilers. I. Model Boiler Tests on the Corrosion of Mild Steel Tubes in Highly Saline Waters. F. WORMWELL, G. BUTLER AND J. G. BEYNON. *Trans. Inst. Marine Engrs.*, 69, No. 4, 109-120 (1957) April.

Model boilers have been used to carry out qualitative and semi-quantitative experiments on the corrosion of internally-heated boiler tubes in conditions simulating those in Scotch boilers.

The depth of pitting on mild steel boiler tubes in distilled water with additions of sea water increases with the density of the solution. Increasing the oxygen concentration in the feed water from 4 ml. per litre to 15 ml. per litre also increases the depth and the extent of pitting. Boiler waters of density 2½ oz. per gal. and above become acid under operating conditions.

When the boiler water is kept alkaline by addition of sodium carbonate to the feed water, the depth of pitting is markedly reduced, although measurable pitting is still obtained in waters of density 5 oz. per gal. (1/32). In these conditions an increase of oxygen concentration in the feed water from 4 ml. to 15 ml. per litre does not produce any increase in depth of pitting.

Some evidence was obtained that small amounts of copper in the steel reduce the likelihood of deep pitting and perforation.

Removal of the mill scale by grit blasting or pickling does not improve the corrosion resistance of the tubes.—TIME. 14187

7.6.4, 4.6.2, 6.2.3, 3.7.2

Corrosion in Scotch Marine Boilers. II. Model Boiler Tests on the Influence

of the Copper Content of the Steel on the Corrosion of Tubes in Artificial Sea Water. G. BUTLER AND H. C. K. ISON. *Trans. Inst. Marine Engrs.*, 69, No. 4, 121-128 (1957) April.

Model boiler tests have been carried out to determine the influence of the copper content of the steel on the corrosion resistance of mild steel boiler tubes in artificial sea water. Experiments with steels containing from less than 0.01 percent copper to 0.20 percent have shown the value of copper in reducing the severity of pitting of tubes in the acid conditions that develop in the boiler when the water is not treated.

Of sixty-six tubes with a copper content greater than 0.1 percent, tested with oxygen concentrations of 4 and 15 ml. per litre in the feed water, only one tube was pitted to a depth as great as 30 mils in the standard 8-weeks' test. Of forty-two tubes with a copper content of less than 0.05 percent, ten were severely pitted, five of these being perforated. In all, eighteen of these tubes had pits deeper than 30 mils.

When the pH of the boiler water was maintained at an alkaline value, the pitting was slight and it was not diminished by copper in the steel. The copper appears to stabilize the original mill scale, pitting being largely localized at breaks in this scale.—TIME. 14183

7.6.4

Incrustation-Corrosion-Priming. (In French.) R. RATH. *Centre Belge d'Etude et de Documentation des Eaux*, 3, No. 33, 209-216 (1956).

Some problems existing in boilers at high and at very high pressure. Practical suggestions for the future.—MR. 13318

7.6.4, 4.6.2

Waterside Corrosion in Naval Boilers. W. TESSIN. *Bureau of Ships J.*, 5, No. 2, 18-20 (1956) June.

Most corrosion of steel boiler watersides is caused by dissolved oxygen in the form of pitting. Evidence shows that pitting takes place usually when the boiler is idle. Idle boilers must either be filled with properly treated water or must be emptied and dried out. Methods to reduce moisture in tubes and prevent entry of oxygen in boilers are listed. Discussion of procedures to follow to cut down pitting of boiler waterside surface is given. Photo.—INCO. 12606

7.6.6

Notes on Liquor Circulation in Digesters. J. E. Wilkinson. Paper before Am. Pulp and Paper Inst., 10th Eng. Conf., Houston, November 7-9, 1955. *Tappi*, 39, No. 6, 181A-183A (1956) June.

Description of various types of digesters. Discussion on the design of digester heaters refers to use of nickel steel, stainless steel and Inconel as tube material. Inconel is the best and most economical material to use since it is immune to the corrosive attack of both cooking liquor and inhibited hydrochloric acid used for scale removal. Deposition of calcium carbonate-resinate scale is less rapid on Inconel tubes and required frequently of scale removal is reduced. Type 304 is used for screen construction and all external liquor piping is steel. Digester circulating system is described.—INCO. 12680

7.6.6

Use of Protective Liners in Kraft Digesters. J. A. ADAMS, D. E. COVEY AND C. H. RIMMER. Paper before Canadian Pulp & Paper Assoc., Ann. Mtg. of Tech.

Section, Montreal, January 23-25, 1957. *Paper Trade J.*, 141, No. 17, 22-28 (1957) April 29.

A studded liner that is easily and cheaply installed at a cost of \$3.64 per square ft. and is easily renewable has successfully answered problem of kraft digester corrosion at Consolidated Paper Corp. Corrosion rate on parent shell protected by studded liner is 0.010-inch per year compared to a previous corrosion rate of 0.046-inch per year on unprotected shell plate. Inconel liners gave excellent corrosion resistance but cost was too high. Studded liner plates gave excellent pulp buildup, shell suffered insignificant metal loss, stud weldment had not deteriorated and studded plate had scaled up completely and did not seem to be suffering corrosion to any measurable degree. Stud assembly consists of a 1 x 3/4-inch 304 stainless steel stud, a 3/8-inch 316 stainless nut and a 1.8-inch 304 stainless cotter pin. Welding rod used to attach stud to shell is 316 titanium coated stainless. Mild steels used as studded liner include a low alloy mild steel plate containing 0.5 each of copper, chromium and nickel. Photos, graphs, tables.—INCO. 14077

7.7 Electrical, Telephone and Radio

7.7, 1.7.3, 4.5.3

Testing Methods and Corrosion Control Measures for Buried Telephone Cable. DANIEL R. WERNER. *Corrosion*, 13, No. 5, 338t-344t (1957) May.

Most of the thousands of miles of buried telephone cable installed by the Bell System have been placed within the past 10 to 15 years. Although relatively few serious corrosion troubles have been experienced on these cables to date, investigations have indicated that damage due to corrosion on this type of plant may be expected to increase unless special mitigative measures are employed.

The number of miles of cable involved has made desirable the development of special layout records which will serve as a base for recording such field data as potential of cable to reference electrodes, sheath current flow measurements, location of corrosion troubles, etc. One such record developed by the author is described.

The difficulty involved in obtaining access to buried cable at the frequent intervals desirable for measurement of current flow on the cable sheath has led to consideration of other means of testing to more precisely locate areas of current loss and the amount of current discharge to the soil. Testing methods now under field trial by the author are discussed.

Utilization of data obtained by the above methods to determine the probable life of a cable from a corrosion standpoint and for balancing the estimated cost of remedial measures for an expected cable life against the cost of replacing the cable at some future date are also described. 13927

7.7, 4.5.3

A Review of Telephone Cable Corrosion Problems with Some Suggestions for Improved Methods in Making Surveys of Bare and Ducted Cables. W. W. ELLEY. *Corrosion*, 13, No. 10, 134, 136-137 (1957) October.

Usual practice in laying bare telephone cable in soil and running cables in ducts is described. Common types of

cable employed are listed and described briefly. Location of and reasons for location of test points on various kinds of cables and installations are described. Adoption of the copper sulfate/copper reference electrode in preference to the lead slug electrode by many telephone companies is ascribed to changed conditions on underground lead cable. Difficulties associated with measurement of small currents are described as are several methods of measuring potentials of cables underground. Economic significance of corrosion damage on long line cables is increasing because of the numerous circuits involved in an outage. 14224

7.8 Wires and Cables (Non-Electrical)

7.8

Characteristics and Application of Round, Flattened and Locked Strand Ropes. H. HITCHEN. Paper before Mining Soc. of Nova Scotia, Ingonish Beach, June, 1957. *Trans. Can. Inst. Mining Met.*, 60, 167-175 (1957); *Can. Mining Met. Bull.*, 50, No. 541, 281-289 (1957) May.

Discussion of working capacity of different types of ropes for various engineering and mining duties. Most mining ropes are made from steel possessing mean tensile strengths of 118 tons/in.² and 130 tons/in.² All ropes are subject to corrosion in varying degrees through action of atmospheric moisture, shaft water and chemical fumes which may lead to breakage of wires and early discarding of winding ropes. Certain shaft waters contain notable quantities of salts in solution, acids or alkalis, which considerably increase corrosive action on steel. Use of ropes manufactured from steel with a rust-resisting zinc coating has considerably increased rope life without any changes being made in mechanical conditions. To counter corrosion, stranded winding ropes are covered with oil which penetrates into interior of a stranded rope. Such thin oils should preferably contain a corrosion inhibitor. Characteristics of various ropes and rope installations are discussed. Photos, graphs, photomicrographs, tables.—INCO. 14289

8. INDUSTRIES

8.3 Group 3

8.3.3, 7.5.5

Bulk Milk Cooler Field Studies. C. N. TURNER. Cornell Univ. Paper before Am. Soc. Agr. Engrs., Chicago, December, 1955. *Agr. Eng.*, 38, No. 2, 94-97, 100 (1957) Feb.

Field studies of bulk milk-coolers on farms in six states are given. Conditions of inside metal surface on all milk-tank liners was good. Deposits of milkstone and/or dried milk were observed but this was a temporary condition. Stainless steel surfaces were found to be in excellent condition but tanks with painted steel exteriors showed varying degrees of chipping, peeling and wear that frequently resulted in rust spots. Rust was found over welded material used to join seams, hinges or various parts of tank components. Rusty areas were also common on underside of tanks near milkhouse floor. Tables, photos.—INCO. 13863

8.3.4, 2.3.7, 5.3.2

On Corrosion of Wine Bottle Caps Made of Thinly Tinned Lead (Tinfoil) and Their Testing. G. SCHIKORR AND K. G. BERGNER. *Werkstoffe u. Korrosion*, 8, No. 1, 1-6 (1957) Jan.

Methods developed for determining thickness and porosity of tin coatings on tinfoil caps are described. Tin layers of commercial wine bottle caps were found to be less than 0.001 mm and considerably porous. Laboratory experiments and practical storage tests were carried out with commercially capped bottles. Depending on conditions, some caps corroded considerably while others were deteriorated completely in contact with wine. Corrosion products were identified as lead salts. Graph shows potential of lead, tin and tin-coated lead in wine.—INCO. 13831

8.4 Group 4

8.4.5, 6.3.20

Corrosion Properties of Zirconium-Base Fuel Alloys. S. KASS. U. S. Atomic Energy Commission Pubn., WAPD-136, November 2, 1957, 41 pp.

Zirconium-base alloys were studied in 680 F water and in steam at 750 F and 1500 psi. The corrosion of zirconium alloys with 4 to 15% uranium follows a course of initial formation of an oxide film, film breakdown and general spalling. The corrosion resistance decreases with higher contents of uranium, but tin improves the corrosion resistance of the alloys. Using Zircaloy-2 instead of zirconium gave no improvement. Adding up to 1% iron had bad effects on the corrosion properties of zirconium-uranium-tin alloys. The 4% uranium, 8% niobium alloy shows promise as a corrosion resistant fuel alloy.—MR. 14302

8.4.5, 6.4.2, 6.4.3, 6.4.1

Corrosion of Aluminum and Beryllium by MTR Canal Water. J. B. BURNHAM, JR. AND M. H. BARTZ. Phillips Petroleum Co. U. S. Atomic Energy Comm. Pubn., AEC-D-3923, Jan. 14, 1953 (Declassified with deletions Jan. 5, 1956), 12 pp. Available from Office of Technical Services, Washington, D. C.

In order to control the excessive corrosion of beryllium and aluminum encountered in early operation of the MTR canal a corrosion testing program was initiated. In a series of beaker tests the effects of adding inhibitors and varying the pH of the raw water were investigated. Sodium dichromate and sodium nitrate were both effective as corrosion inhibitors. The corrosion resistance of aluminum to raw water improved as the pH was reduced from 8.1 to 6.0. Adjustment of the pH with nitric acid rather than sulfuric acid proved much more effective in reducing corrosion rates. Aluminum showed good corrosion properties in demineralized water in the pH range of 8.1 to 6.0; the corrosion resistance was superior, though, in the lower pH water. A recommendation was made to use demineralized water of pH 7.0 in the canal. Aluminum and beryllium samples tested for 6 months in this water showed good corrosion resistance. (auth).—NSA. 13975

8.5 Group 5

8.5.3, 4.3.4, 6.2.3

Corrosion Studies of Carbon Steel in Alkaline Pulping Liquors by the Poten-

tial-Time and Polarization-Curve Methods. Pt. II. Mixtures of White with Oxidized or Non-Oxidized Black Liquor. W. A. MUELLER. Paper before Am. Pulp and Paper Inst., 11th Eng. Conf., Boston, Oct. 8-11, 1956. *Tappi*, 40, No. 3, 129-140 (1957) March.

Experiments were carried out on carbon steel samples of high silicon content. Influence of secondary factors on polarization curve are discussed. Equation for calculation of depolarization potential curve is derived and valency of iron in sulfide is discussed. Polarization curves, corrosion-potential curves and depolarization curves are measured for mixtures of white liquor with oxidized and nonoxidized black liquor. Maximum of corrosion-potential curves falls rapidly with increased black liquor to white liquor ratio; simultaneously depolarization current rises with increased addition of black liquor, particularly with oxidized black liquor. Effects of additions of dimethyldisulphite, thiosul-

phate and pyrogallol are shown. Polarization curves of initial phases of laboratory cooks up to 100 C are given. Hypothesis for mechanism of kraft liquor corrosion and type of depolarizing agents is proposed. Corrosion is stopped at certain phase of cook when depolarizing current overtakes corrosion current and potential shifts to passive range. Oxidation of black liquor before mixing with white liquor increases depolarizing effect and corrosiveness in mixtures of low black-to-white ratio. Feasibility of anodic or cathodic protection is discussed. Graphs.—INCO. 13869

8.5.3, 5.2.1

Cathodic Protection in Pulp and Paper Mills. J. A. LEHMANN. Paper before Am. Inst. Elec. Engrs., Tech. Conf., Atlanta, March 28-29, 1957. *Paper Trade J.*, 141, No. 15, 64-66, 67-68 (1957) April 15.

Discusses use of cathodic protection on structures throughout paper mills to control corrosion losses and produce profits. Causes of galvanic corrosion, application of cathodic principle and choice of right anode material and current requirement are discussed. Besides use of cathodic protection, thorough consideration should be given to use of protective coatings, chemical treatment and use of proper alloys and plastics. Diagrams, table.—INCO. 14066

8.8 Group 8

8.8.1, 6.2.5

Use of Stainless Steel to Combat Corrosion in the Chemical Industry. Parts I, II. C. P. DILLON. *Corrosion*, 13, Nos. 9, 10, 124, 126, 128, 130, 132, 134, 136-138; 138, 140, 142, 144, 146 (1957) September, October.

After discussing briefly reasons for the corrosion resistance of stainless steels and some of the environments in which it corrodes readily, the author describes maintenance and structural errors which can cause rapid corrosion. Some errors in the customary concept of oxidizing and reducing conditions are noted. In a discussion of specific types for specific services an understanding of the meaning of specifications is urged, with the observation that variations in process streams are more significant than minor alloy variations. Some errors in assessing the meaning of quality control tests are enumerated and relative values of tests and metallographic examinations considered. Behavior, sometimes unexpected, of some alloys in screening tests is considered.

In a discussion of welded specimens reasons for not using them in quality control tests are enumerated. A specification for drawn welded tubes in services commonly associated with seamless tubing is described.

Behavior of some steels is described in acetic acid, sulfuric acid, caustic, sulfurous acid, phosphoric acid and nitric acid environments. Reasons for using stainless in some cooling waters are given and dangers associated with their use explored.

Characteristic defects of stainless materials are considered with special emphasis on sensitization and stress-corrosion cracking. The author considers concepts of emphasis on sensitization overemphasized and believes stress-corrosion cracking to be more common than is indicated in literature. Illustrations of stress-corrosion cracking are given.

tions of stress-corrosion cracking are given.

Recommendations on fabrication include proper selection of rod analysis, quench phenomena and welding repairs.

Some comments are included on corrosion testing, including size of specimens and apparatus for inserting in process streams. 14262

8.8.4, 6.4.2

Tests on the Application of Aluminum in the Manufacture of Tanning Materials. (In Hungarian.) MARIA HOLLO GYENES. *Kohászati Lapok*, 11, 475-478 (1956) Oct.

Investigation to determine the resistance of aluminum to various compounds during tanning-materials production. Experimental arrangement. Materials investigated.—BTR. 13998

8.8.5

Analysis of Failures for Steel Mill Maintenance. J. V. RUSSELL. Republic Steel Corp. *Iron Steel Engr.*, 34, No. 4, 142-146 (1957) April.

Discusses wear, brittle fracture and fatigue failures encountered in mill equipment. Wear and brittle fracture are minimized by proper materials and treatment. Examples cited are worn C1040 (200 BHN) chain link and pin assembly replaced with carburized and hardened low-carbon alloy spring steel link; and use of carburized and hardened alloy steel for gears. Brittle fracture is illustrated by failures in hoist hooks. Fatigue failures are discussed with reference to alloy steel axle shaft where fatigue crack originated at tack weld and straightener drive shaft made of C1045 steel.—INCO. 14131

8.9 Group 9

8.9.1

Surface-Protection and Cooling Systems for High-Speed Flight. D. J. MASON and C. GAZLEY, JR. Paper before Inst. Aeronaut. Sci. Los Angeles, June 18-21, 1956. *Aeronaut. Eng. Rev.*, 15, No. 11, 46-55 (1956) Nov.

Discusses systems for surface protection against transient and continuous heat inputs, corresponding to typical missile and aircraft flight paths. Applicability and relative efficiencies of each of the following systems is considered: Thickening of skin, insulation of outer skin surface, cooling of inner skin surface, insulation and internal cooling, transpiration cooling, and mass-transfer cooling. Graphs show effective increase in weight required to withstand effects of high equilibrium temperature for Inconel X, RC-130A titanium alloy and several Al alloys operating in compression and in tension. Logarithmic bar graph summarizes heat absorption of various metals including nickel.—INCO. 14093

8.9.1, 5.4.8, 5.6.3

Progress in Prevention of Corrosion in Naval Aircraft. S. L. CHISHOLM and N. N. RUDD. *Corrosion*, 13, No. 7, 473-480 (1957) July.

Most naval aircraft, because of the corrosive environment in which they are employed, require the best available surface protection. Thin resin and lacquer films have exhibited good metal adherence and excellent resistance of protected parts to marine weathering. Many magnesium alloy components are



TECHNICAL REPORTS on CORROSION in UTILITIES

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effectively protected by high bake silicone resin formulations. Pigmented silicone resin coatings on engine cases and numerous other cast magnesium aircraft components, have been in operational use for about 3 years with good results. Use of such bake application methods is necessarily limited to certain aircraft parts.

Protection of naval aircraft parts dur-

ing standby and storage periods is now being accomplished by two new approaches, (1) thixotropic preservation formulations (gel structures) and (2) vapor corrosion inhibitors. A group of 22 North Island aircraft engines were carefully preconditioned, ten protected by conventional oil mixtures and twelve by a vapor corrosion inhibitor. The test engines were sent to exposure areas

ranging from arctic to tropic conditions. After only six months, the engines protected by oil mixtures showed serious cylinder wall corrosion while those protected by the vapor corrosion inhibitor were still in acceptable condition after 18 months.

13900

8.9.1, 6.3.15

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Temperature Applications in Airframes: Supplement, S. A. GORDON AND L. R. JACKSON. Battelle Institute, Feb., 1956, 30 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington, D. C. (Order PB 121602).

A considerable amount of general information for design of air frames was derived from crippling tests on channel and angle sections on C-110M titanium alloy at temperatures to 800 F. The results of the tests were used to calculate the structural index which was compared with the theoretical structural index through data from the compressive stress-strain curves of the materials involved. Although the work supplied valuable basic design data, it pointed up a need for a more reliable method of comparing materials at high temperature. 13991

8.9.3, 1.2.2

Long Range Preventive Maintenance Plan for Steel Gas Mains. A. E. SCHMITT. Southern Calif. Gas Co. *Gas*, 33, No. 2, 49-53 (1957) Feb.

Key to successful operation of efficient pipeline is adoption of a long range preventive maintenance program. Discussion given of plan includes a leakage investigation program, a main replacement program geared to actual rate of pipeline deterioration and corrosion control program by use of cathodic protection and coatings. Typical maintenance flow chart is given. Graph shows maintenance cost study of pipe

placed under cathodic protection. Diagrams.—INCO. 13833

8.9.3

Corrosion Protection for Oil Pipe Lines. D. M. ALLAN AND J. S. GRAY. *Chem. Can.*, 9, Nos. 5, 6, 35-38; 76, 78, 80, 86 (1957) May, June.

Discussion of importance of corrosion protection for Trans Mountain Oil Pipe Line Co. operations in western Canada. Coating conductance, casings and insulating flanges are described and graphs and interpretation of potential measurements on Trans Mountain's oil pipe line in the Fraser Valley, B. C. are given. Diagrams.—INCO. 14184

8.9.3, 1.2.2, 5.2.1

Economics and Effectiveness of Cathodic Protection on Large Diameter Pipelines. N. K. SENATOROFF. Southern Counties Gas Co. *Petroleum Engr.*, 29, No. 3, D26-D29 (1957) March.

Discusses preliminary study of costs of corrosion protection as applied to proposed reconditioning of section of 26-inch outside diameter high pressure natural gas transmission line in San Joaquin Valley. Use of cathodic protection (electrical drainage) did not reduce frequency of leak repairs. Pipeline was reconditioned by welding up individual pits and by application of thicker coal-tar enamel. Tables illustrate difference in cost for cathodic protection, before and after reconditioning; economy of

using coal-tar enamels with high electrical insulation in conjunction with cathodic protection is shown.—INCO. 13859

8.9.5

The Corrosion of Cargo Ships and Its Prevention. H. J. ADAMS AND J. C. HUDSON. Paper before Inst. Naval Architects and Inst. Marine Engrs. Jt. Mtg., March, 1956, 20 pp. *Corrosion Prevention and Control*, 3, No. 6, 41-45 (1956) June; *Trans. Inst. Marine Engrs.*, 68, 429-459 (1956) Nov.

Effect of steel quality, design and welding on corrosion; underwater, super-structure and internal corrosion; painting; use of metallic coatings (galvanizing, aluminum spraying); cathodic protection; Rules of Lloyd's Register relating to corrosion.—BNF. 13958

8.9.5, 5.2.2

Cathodic Protection of Internals of Ships. L. P. SUDRABIN. *Corrosion*, 13, No. 7, 466t-472t (1957) July.

Information obtained in connection with the application in ships of cathodic protection to internal tanks used for sea water ballast is discussed in detail. Particular attention is given to: (1) diagnosis of the corrosion problem, (2) design and application of protective current, and (3) measurement of the protection achieved. It was found that the required corrosion control could be achieved by coordination of the cathodic protection design and the ballast practices.

Advantages and disadvantages of panel tests are listed. Techniques used in evaluating the protection obtained on the internal bulkhead, skin and structural member surfaces by non-destructive testing are described. A corrosion mechanism is discussed briefly.

Cost of cathodic protection for adequate corrosion control of the internal cargo ballast compartments of vessels was found to range from \$.02 to \$.10 per square foot per year. 13897

8.9.5, 8.2.2, 4.6.10, 4.6.2, 4.2.3

Corrosion Problems of Naval Steam Power Plants. R. C. ADAMS. Paper before Am. Power Conf., 18th Ann. Mtg., Chicago, March 21-23, 1956. *Proc. Am. Power Conf.*, 18, 583-590 (1956).

Hot, concentrated evaporator brine is corrosive because of its mild acidity and the multiplicity of ions available for new combinations. Periodic chemical cleaning to remove deposits is effective in maintaining evaporator capacity. Adequate resistance to cleaning chemicals is achieved by employing Admiralty brasses for low pressure evaporators and Monel for vapor compression stills. The only storage tank metals which were found sufficiently inert to prevent intolerable concentrations of these ions are tin and stainless steel. While Monel tanks are sufficiently corrosion resistant to endure practically forever, the few ppm of copper and nickel leached from their surfaces by distilled water are poison to storage batteries. Acidity, alkalinity and oxygen cause corrosion in boilers and slagging, sootblowers, water washing and soot cause corrosion on boiler firesides. Superheater supports, even when made of such high alloy materials as 25-20 chromium-nickel, attain such high temperatures that they react with slag constituents and rapidly waste away. Corrosion prevention methods for the various causes are discussed.—INCO. 13913

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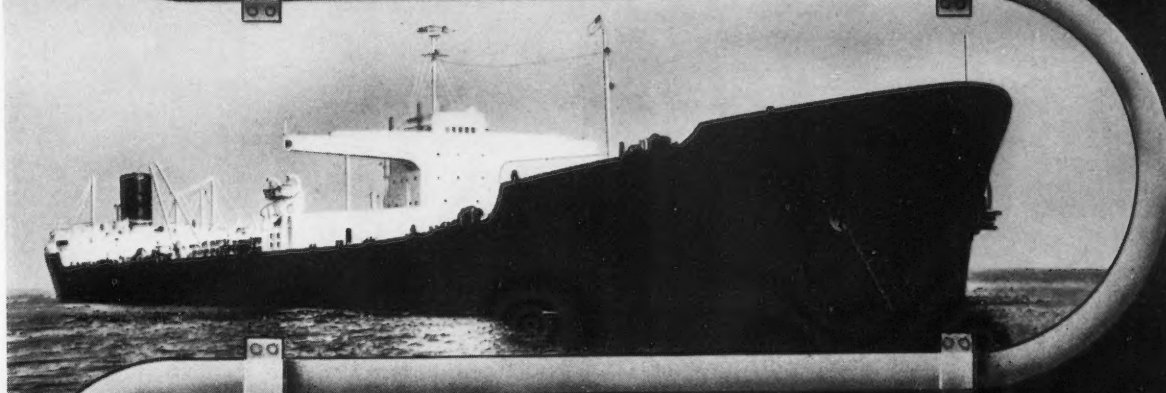
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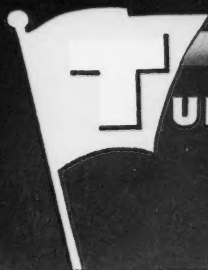
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from corrosive contact of hot, sour crude
oil and salt water ballast, the Nippos-coated heating
coils of National Bulk Carrier's newest tanker promises
to outlast ordinary coils by several years!

The new Nippos Process, exclusive with Tube Reducing,
makes any ferrous metal as corrosion-resistant as high-priced
stainless for many applications. Applied on any shape —
fused and alloyed in place by heat treating — Nippos-clad
metal can outlast untreated ferrous as much as 10 to 1!

Write or call today for complete details,
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Fluoroflex®-T Molded Bellows

LAST FAR LONGER



*because they're made of
TEFLON® at its best*

Molded, not machined for continuous, undamaged grain structure

Special compound developed for maximum flex life

High density, non-porous

Chemically inert, universally useful, non-contaminating

BELLOWS MOLDED OF FLUOROFLEX-T offer at least 20 times the flex life and twice the burst strength (after flexing) of ordinary bellows machined from Teflon. At long last, you have chemically inert flex joints with predictable service life, even under extreme conditions.

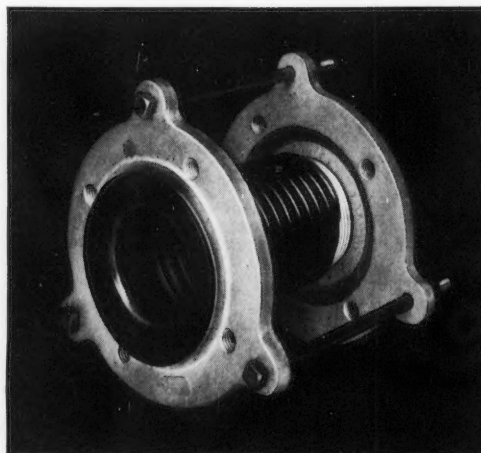
FORGET ABOUT SUDDEN FAILURES — COSTLY DOWNTIME. One big user severely flexed Fluoroflex-T bellows 20,000,000 times...abandoned the test without a failure.

Even at 400°F., tested through *maximum* expansion range under full *dynamic* working pressure...bellows went through 100,000 cycles before tests were discontinued...still without failures.

NEW BULLETIN TELLS MORE—gives operating and construction data. Write RESISTOFLEX CORPORATION, Roseland, New Jersey. Southwestern Plant, Dallas, Tex. Western Plant, Burbank, Calif.

® Fluoroflex is a Resistoflex trademark, reg., U.S. pat. off.

® Teflon is DuPont's trademark for TFE fluorocarbon resins



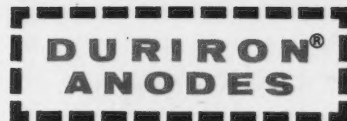
Complete systems
for corrosive service

RESISTOFLEX



LINED STEEL PIPE • FLANGED FLEXIBLE HOSE • BELLOWS • ELBOWS • TEES • REDUCERS • DIP PIPES & SPARGERS • LAMINATED PIPE

For superior protection of underground structures



**3 year-old installation
jetted in**

WITHOUT BACKFILL

shows no loss of protection

This actual installation graphically demonstrates Duriron's ease of installation and economy factors.

Twenty Duriron Anodes were installed to protect a pipe line in a creek bed area where sandy soil prevented backfilling. These anodes were jettied into place in the vertical position using a high velocity stream of water, and were placed with the top of the anodes 3 feet below the surface. *Each anode was in position within 60 seconds.*

The group of anodes produced an average of 33 amps at 36 volts with no tendency to gas block. Actually, the bed resistance has decreased since the original installation. There was considerable cost-saving in the elimination of carbonaceous backfill.

- * Duriron anodes, bare or with backfill, resist all current densities common to ground bed applications.
- * Duriron resists all soils. Care required only when operating at high current densities in high chloride areas.
- * Duriron has dense structure. Will not absorb moisture or gases causing breakdown. High weight factor gives longer life per anode size.
- * Duriron has good electrical conductivity. Minimizes heavy current discharge near connection for uniform consumption.
- * Duriron is mechanically strong. Metal-to-metal contact avoids loss of protection due to poor connection.

THE DURIRON COMPANY, INC.
DAYTON, OHIO



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For superior protection of underground structures



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